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SOUTHERN CALIFORNIA

Prepared under the direction of

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CONTENTS

ILLUSTRATIONS

INSERTS

From "Mining in California," 1931. Photograph used by permission of H. A. Sedelmeyer. Dotted lines show routes of excursions. 1, Klamath Mountains; 2, Columbia-Cascade province (2a, Cascade Range; 2b, Modoc Plateau); 3, Sierra Nevada; 4, Great Valley; 5, California Coast Ranges; 6, Basin and Range province (6a, Great Basin; 6b, Mohave Desert; 6c, Salton Trough); 7, Lower California province.

SOUTHERN CALIFORNIA

Prepared under the direction of Hoyt S. Gale

GEOLOGY OF SOUTHERN CALIFORNIA

By Hoyt S. Gale

DISTINGUISHING FEATURES

The geology of southern California is distinguished from that of the central and northern parts of the State chiefly because it exhibits more extensively and in more complete and consecutive sections the marine stratigraphy of the Tertiary and Quaternary systems. The northern boundary of this region is marked to a certain extent by an offset of the Coast Ranges. The Tertiary basins of deposition seem to have been deeper and more extensive in the southern half of the State than farther north.

RELATION TO CORDILLERAN SYSTEM

Southern California occupies a relatively minor subdivision of the great structural complex of mountains, high plateaus, and plains known as the North American Cordillera. The western division of the Cordilleran major province, which is sometimes referred to as the Pacific system, is itself complex, including a varied assortment of mountain ranges that stretch in almost continuous alinement from Alaska to the peninsula of Lower California. In this Pacific system southern California occupies a fairly distinct section, separated from the sections to the north and to the south by a marked difference in the structural trends, as indicated by the transverse ranges shown on Plate 1. The transverse ranges include the Santa Ynez Range of the Santa Barbara coast, the Topatopa, Santa Monica, and San Gabriel Mountains, and, in part at least, the San Bernardino Mountains. Besides the transverse ranges and the intervening basin areas, southern California includes the Mohave Desert portion of the Great Basin and the north end of the ranges that extend northward from the peninsula of Lower California.

SIGNIFICANCE OF PRESENT GEOMORPHIC FORMS

Many of the major structural features in this region are extremely young. The present relief and the arrangement of geographic units are to a very large extent the products of a mountain-building revolution that took place within the Pleistocene epoch.

The greatest periods of diastrophic revolution in the southern part of the State have been, first, the Cordilleran revolution, characterized by compressional deformation of the whole Cordilleran province and probably also a much more extensive area, which for the Pacific border is identified in time with the later part of the Jurassic; second, the mid-Miocene revolution, which broke up the eroded remnants of the older topography and drainage systems and established a new and rugged land surface; and third, the last great deformation, which occurred near the middle of the Pleistocene epoch.

THE GEOLOGIC RECORD

The remains of Paleozoic and early Mesozoic sedimentation are exceedingly fragmentary in southern California. Shattered masses of old quartzites, slates, and massive limestones, locally revealing diagnostic fossils, indicate that the Paleozoic was originally more completely represented along the Pacific coast than it is now, and its present fragmentary preservation, in contrast with the more complete sections exposed in the High Plateaus and Rocky Mountain region farther east, may be due to the more strenuous structural history that the Pacific coast has undergone since these rocks were laid down. In places there are small areas of Triassic and Jurassic deposits, chiefly dark-gray and black slates with interbedded brown sandstones and associated volcanic rocks.

The Cordilleran deformation.—At some time culminating in the late Jurassic the great deformation by which the older Pacific mountain system was produced compressed the whole area of geosynclinal deposition of the Paleozoic and earlier Mesozoic, together with the included igneous rocks, into a series of northwestward-trending folds.

Batholithic intrusions were associated with this deformation. The magmas invaded and absorbed or metamorphosed large masses of the earlier sediments and are included with the "Basement complex." These rocks form the core and main mass of the Sierra Nevada, as well as a large part of the transverse and peninsula ranges, and are exposed at lower altitudes in some of the older peneplain surfaces, especially the remnants of Tertiary topography such as are found in the Mohave Desert.

It may be assumed that the greater part of the Cordilleran revolution was accomplished in this region near the end of Jurassic time. The interpretable record in southern California, however, may be said to begin with the Cretaceous—really with the Upper Cretaceous.

Postdeformation period.—The Cretaceous seas covered the site of the present Rocky Mountains on the east as well as the Pacific coastal belt on the west. It is probable that at first the mountains were not elevated to very great heights, for in many areas the Lower Cretaceous sediments consist of fine-grained materials, derived presumably from the sedimentary rocks that covered the batholiths. Little of the Lower Cretaceous is represented in southern California. Perhaps this part of the country remained above sea level during Lower Cretaceous time. Not until Upper Cretaceous time, represented in southern California by the Chico formation (see pl. 2), were there any considerable deposits of coarse-grained materials. By Chico time granitic masses must have been exposed over large areas, because the deposits formed from then on contain a large amount of fresh granitic detritus. The topography of that time was probably similar to that of to-day, with high fault scarps and flat basins of deposition below. Large boulders bear witness to the steep slopes; but the coarse to fine, massively but irregularly bedded sandstones and shales indicate that the places of deposition were comparatively level, like the floors of the present intermont basins. The deposits were at least partly marine along the Pacific coastal belt, although fossils are on the whole not abundant. The sea encroached upon the sinking fault blocks in a belt extending from Central America to Alaska, but probably nowhere in California did it reach more than 100 miles (161 kilometers) east of its present position.

The end of the Mesozoic and beginning of the Tertiary in this part of the continent was not a period of violent orogenic deformation, as in many other parts of the world.

Early Tertiary paleogeography.—Unconformities and coarse detrital deposits indicate that recurrent crustal movements followed the Cretaceous period. However, it seems quite certain that no one of these was of anything like the extent or magnitude of the late Jurassic deformation. We may therefore draw the generalized picture of the high mountainous masses and rugged topography which had been produced in the later part of the Mesozoic era, deeply worn down during Cretaceous time. Erosion in general continued throughout Eocene, Oligocene, and at least the first half of Miocene time. In southern California

there is abundant evidence of this long period of degradation of the land surfaces, which produced by middle Miocene time lowlands in the interior districts that were carved over the remnants of the older rock masses. Most of the area now occupied by the Sierra Nevada, with the broad expanse of the Mohave and adjacent desert areas and other areas that now exhibit irregular topography bordering the narrow Pacific coastal strip, was undergoing degradation during the greater part of this time. The early Tertiary was essentially a period of erosion almost to the stage of peneplanation for all of southern California except the relatively narrow belts of marine sedimentation that mark the Eocene, Oligocene, and early Miocene along the Pacific coast. There were, of course, zones intermediate between the areas of degradation on the one hand and the areas of marine deposition on the other, in which terrestrial deposits accumulated, and these zones became more extensive as the land surface lowered in Oligocene and early Miocene time.

Eocene.—At several places the borders of the Eocene seas may be seen in the littoral phases of their deposits, reaching back from the present coast of the Pacific into the interior. Eocene seas evidently reached inland across the site of the present San Gabriel Mountains to the border of the Mohave Desert and extended thence northward approximately along the western foot of the present Sierra Nevada. The sediments of Eocene age resemble in composition those of the Cretaceous, including sandstones, sandy shales, and in places conglomerates, the whole chiefly the product of decomposition of granitic rock.

Oligocene.—The record of the Oligocene in southern California is much more meager than that of the Eocene, which preceded, or of the Miocene, which followed. Land-laid deposits, characteristically stained red or brown, as if derived from materials long weathered, with decay and oxidation of their minerals, occupy extensive areas in Ventura County, and it is reported that an abundant and diagnostic vertebrate fauna shows them to be Oligocene, at least in part. Certain marine shales at the south end of San Joaquin Valley and along the Santa Barbara coast are also considered to be of Oligocene age. The shore of the Oligocene sea seems to have retreated outward from the farther inland advances of Eocene time, and the Oligocene land seems to have been similar in area and position to that of the present day, at least so far as southern California is concerned.

Miocene.—The Miocene epoch began with a gradual transgression of the sea from a shore line near or beyond the present continental border inland to the approximate limits that had been reached by the Eocene marine invasions. The deposits of this

		South slope eastern Santa Ynez Range	Santa Clara Valley	Simi Valley	Los Angeles Basin: Eastern Santa Monica Mts.	Los Angeles Basin: Elysian Hills, Repetto Hills, Puente Hills	Los Angeles Basin: San Pedro Hills	Faunal zones: Foraminifera	Faunal zones: Other fossils
PLEISTOCENE		Terrace deposits; Saugus formation	Terrace deposits; *Saugus formation	Saugus formation	Terrace deposits	Saugus formation	*Palos Verdes sand; Older terrace deposits; *San Pedro sand; Silt; Calcareous beds	Elphidium crispus	Trachycardium procerum; Margarites optabilis; "Pecten" caurinus; Crassatellites fluctuatus
PLIOCENE	Upper	Pico formation	*Pico formation	San Diego formation[d]	Pico formation; San Diego[d] ss. member	Pico formation		Uvigerina aff. tenuistriata; Cibicides mckannai; Uvigerina peregrina; Bulimina subacuminata	Crepidula princeps; "Pecten" healeyi; Astrodapsis fernandoensis
	Middle							Plectofrondicularia californica	Lima hamlini
	Lower		Repetto formation[c]		Repetto formation	*Repetto formation	Repetto formation	Arenaceous fauna	
MIOCENE	Upper	Modelo formation[a]	*Modelo formation[a]	Modelo formation[a]	Modelo formation[a]	*Puente formation[a]	Modelo formation[a]	Bolivina hughesi; Valvulineria californica-Nodosaria koina	Astrodapsis aff. brewerianus
	Middle	*Rincon shale	Rincon shale; Topanga formation	Rincon shale; Topanga formation	*Topanga formation		Topanga formation	Plectofrondicularia miocenica; Siphogenerina mayi	Turritella ocoyana
	Lower	Vaqueros sandstone	Vaqueros sandstone	Vaqueros sandstone; ?	Vaqueros formation (?) or Sespe formation (?)				Turritella inezana
OLIGOCENE	Upper	Sespe formation	*Sespe formation	Sespe formation	?				
	Middle								
	Lower								
EOCENE	Upper		?						
	Middle	Tejon formation: *Coldwater sandstone[b], *Cozy Dell shale[b], *Matilija sandstone[b]		?				Discocyclina clarki	Turritella lawsoni
	Lower	Undifferentiated Eocene		Domengine formation[b]; Santa Susana shale[b]					Turritella meganosensis
	Basal or Paleocene[b]			Martinez formation	Martinez formation				Turritella pachecoensis
CRETACEOUS	Upper	Undifferentiated Cretaceous		Chico formation	Chico formation				
	Lower								
JURASSIC	Upper						? Franciscan formation (?)		
	Middle								
	Lower								
TRIASSIC	Upper								
	Middle				? *Santa Monica slate				
	Lower								

Vertical ruling shows absence of deposits

SEDIMENTARY DEPOSITS IN AREAS COVERED BY EXCURSIONS IN COASTAL REGION OF SOUTHERN CALIFORNIA

Compiled by W. P. Woodring with the assistance of D. D. Hughes and S. G. Wissler.

A question mark before a name signifies that the stratigraphic position is doubtful; one after a name signifies that the designation is doubtful.

* Type region.

a Monterey shale of many California geologists.

b Names that have not been adopted by the United States Geological Survey.

c The Santa Paula formation of Eaton, the type locality of which is in this region, as originally defined embraces deposits of late Repetto and early Pico age.

d The position of the San Diego formation with reference to foraminiferal faunal zones has not been satisfactorily determined.

epoch are marked by a formation of arkose sands and conglomerates at the base of the section, which contains a distinct littoral fauna, and this facies has been traced from the present coast inland for many miles. The low relief of preceding epochs continued to yield fine earthy sediment, which formed also a shaly section, and this is usually classed with the basal conglomerate and is known as the Vaqueros formation. However, similar deposits succeeded in the deepening sea, and locally in California an upper part of this series has been distinguished under the name Temblor formation. These two parts of the lower and middle Miocene section have been distinguished chiefly by faunal differences. The lower or Vaqueros deposits have been called the *Turritella inezana* zone, and the later or Temblor deposits the *Turritella ocoyana* zone.

At some time while the sea was advancing, or as a culmination of this movement, which if the subsidence is assumed to have been slow may have extended to about the middle of the Miocene epoch, there came a widespread and very significant diastrophic movement. Unlike the revolution of late Jurassic time, which was characterized by intense folding of the compressional type, the mid-Miocene revolution seems rather to have been characterized chiefly by faulting, at least throughout the areas of the more brittle crystalline rocks. At the same time there may have been folding in the less resistant sedimentary beds along the coast.

It appears that these orogenic disturbances began abruptly, not only in southern California but probably in the major part of the Great Basin and Pacific provinces. Throughout the great area that had remained above the sea and had been undergoing degradation during the earlier part of Tertiary time there is recorded a sudden breaking up of the older topography, with dislocation of preexisting drainage systems almost in their entirety. The continental interior now became a series of closed basins. The products of disintegration that had formerly been passed on to the ocean were now trapped in separated basins, each with its independent drainage system. The dislocations effected also similar displacements in the earlier Tertiary marine deposits along the coast, with consequent redistribution of the sediments of the uplifted blocks.

These events are recorded in the abrupt change of texture of the deposits of approximately the same age which may be observed in many scattered localities. The most significant change is, of course, the coming into the section of coarse conglomerates, succeeding the finer deposits that represent most of the preceding middle Miocene. The Temblor formation is rep-

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resented in many places by massively though regularly bedded coarse sandstones, perhaps indicating some crustal adjustments preceding the more violent break-up. However, the main movements are indicated by the basal conglomerates that lie on the eroded surfaces of distinctly older rocks and the conspicuously coarse boulder conglomerates that seem to mark abrupt displacement and steep tilting of many fault block masses at about the same time in many places. The date of their beginnings is fixed in the marine time scale at various rather widely separated localities, and the accordance is significant. The date agrees, as closely as may be interpreted now, with the vertebrate record of the interior basins. It came soon after the *Turritella ocoyana* fauna (Temblor), of middle Miocene age. The diastrophism may therefore be called the mid-Miocene revolution. The deposits that followed this revolution vary widely, because of the diversity of the sources from which their detritus was derived.

Shortly after this diastrophism began, and apparently concordant with it in part, volcanic activity broke forth on a large scale. After a long period of volcanic quiescence in this general region, lavas were poured out on the surface, and these with their associated mud flows, breccias, and ash or pumice deposits accumulated locally to immense thicknesses. Along the coastal belt the lavas were sparsely distributed within the thousands of feet of the sedimentary series.

The influence of the widespread volcanic activity of this epoch is seen in the postdeformation deposits in many places. While the dust from the eruptions was being distributed in abundance on the land in the vicinity of the volcanic vents, large quantities of it also fell off the then existing coast on the ocean surface and were laid down as marine sediments, including many organisms. Organic and cherty or silicified portions of the resulting shales made up much of the well-known type of siliceous shale called Monterey shale by many California geologists. These siliceous, pumiceous, and diatomaceous shales have been called by various names in different parts of California, but they are coming to be recognized as closely equivalent. Volcanism continued later in some areas than in others, and therefore the siliceous shales persist through later deposits in those areas. In places there is evidence of continued crustal adjustments, yielding coarse deposits, such as sand and granitic detritus, with or without volcanic débris, which continue locally throughout the later Miocene, but in many sections the so-called siliceous shale with intercalated sandy beds completes the cycle of the Miocene without any significant break.

Pliocene.[1]—The Pliocene in southern California seems to have begun with some crustal movements. In the centers of the larger basins, however, such as the Ventura and Los Angeles Basins, sedimentation seems to have been continuous from the Miocene to the Pliocene. The fauna of the lower Pliocene shows a change of character, although not everywhere a marked change, from that of the upper Miocene. Pliocene sedimentation piled up a tremendous thickness of deposits—more than 20,000 feet (6,096 meters) along the axes of some of the deeper basins—which must have represented a corresponding subsidence of the surface, and this, with the evidence of the shifting shore lines mentioned above, may be interpreted as indicating downward compression, which together with isostatic readjustment must have accounted for many of the lesser uplifts and depressions that are shown throughout the geologic record.

The deposits of the marine Pliocene and Pleistocene, as well as most of the preceding Tertiary marine sediments, were laid down along the continental border in a relatively narrow belt following the present coast and accumulated in their greatest thicknesses in deep reentrant basins. There is some difference of opinion regarding details of the correlation of the depositional units of these stages laid down in the different basins, but at least some main features of broader regional significance stand out in this record.

The Pliocene seems most clearly divisible into three main stages or subdivisions. The deposits of the earliest stage, which was essentially a transition from the preceding Miocene, are lithologically distinct in many areas but have often been classed with the Miocene. Toward the middle of the Pliocene there was, in almost all basin areas along the coast, a subsidence resulting in a marine invasion, which in many places reached a very definite maximum and then rather abruptly withdrew. Throughout this time the climate continued warm, as it had been apparently through most or all of Miocene time.

The lower Pliocene or transition zone is the formation in which most of the commercially important oil accumulations occur in southern California, especially in the Los Angeles Basin. These strata, more commonly represented in the well cores than found in surface outcrops, are not extensive and are usually overlapped by deposits of the sea that transgressed in middle Pliocene

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[1] In the preparation of the account of the Pliocene and Pleistocene history considerable use has been made of a recently published summary of the faunal and stratigraphic evidence on this subject (Gale, H. R., in Grant, U. S., and Gale, H. R., Pliocene and Pleistocene Mollusca of California: San Diego Soc. Nat. History Mem., vol. 1, pp. 19–78, 1931).

time. The name Repetto has been recently proposed to define this unit in and near the Los Angeles Basin. (See p. 31.)

The deposits representing the transgression of the middle Pliocene form the base of the Pliocene section at many outcrops around the borders of the basins of deposition. These shore deposits, locally with an abundant and well-preserved fauna, lap against the uptilted edges or planed-off surfaces of the entire range of the older rocks from the "Basement complex" to the Miocene.

The upper Pliocene was characterized by a very distinct faunal change. With the approaching cold of the glacial epoch extensive migrations of faunas took place, causing the extinction of many species that had been abundant. The deeper submergence of the middle Pliocene was ended by uplift and transition from locally varying open-sea and estuarine conditions to more generally prevalent estuarine and brackish and fresh water conditions.

The middle and upper divisions of the Pliocene are important in an economic way because, in the Elk Hills and Midway-Sunset region of San Joaquin Valley, they are the present source of the greatest oil production.

Pleistocene.—Until a short time ago the lower Pleistocene was generally classed with the Pliocene in California, partly because the Recent fauna was not so well known and many of the species now known to be still living were then thought to be extinct, and partly because the formations of this age were involved along with the Pliocene in the great diastrophic revolution of the late Cenozoic.

The Ventura and Los Angeles Basins, in southern California, are keys for the demonstration of the relations of California Pleistocene deposits. The most intensively studied area is that near San Pedro, in the Los Angeles Basin. Several Pleistocene marine formations are recognized here, which are described in the itinerary of the San Pedro Hills excursion (pp. 36–38). These formations carry faunas of different temperature facies and have been interpreted as representing glacial and interglacial stages.

Not until the middle Pleistocene did the latest great diastrophic revolution take place. It seems, to judge from the tremendous structural features formed and the unconformities produced, that this was of greater magnitude than the middle Miocene deformation. In many places thousands of feet of sediments were faulted, upthrust, folded, and locally overturned. In the Los Angeles Basin the record of such marine deposits as have been studied indicates that the deformation followed the deposition of two cold-temperature series and two milder-temperature series.

It is probable that the main period of folding and overthrusting occurred at approximately the same time throughout California.

Southern California was left with a network system of folded, upthrust, and depressed blocks. The broad terrane of high relief so produced probably extended with about the same character west of the present coast, perhaps nearly to the outer edge of the continental shelf. The western part was probably partly submerged, the higher blocks projecting from the water as islands, much as they do to-day. Some blocks sank, while others started to rise. On the rising blocks, such as San Clemente Island and San Pedro Hill, a dozen or more well-defined wave-cut terraces are found, ranging in height from a few feet above sea level practically to the highest summit, which is 1,480 feet (451 meters) above sea level. On the other hand, Santa Catalina Island, which lies halfway between San Clemente Island and San Pedro Hill, bears no terraces. On the land some valleys are terraced, whereas others are drowned in alluvium. The nearly horizontal position of the terraces indicates that the differential uplift took place after the regional compression and folding had ceased.

The land surface that was developed while the Pliocene and lower Pleistocene sediments were being laid down has been recognized in several places. In southern and middle California the remnants of this older surface are cut or bounded by fault scarps, many of them of high relief, and in this respect are very different from the remnants of most of the oldest postdeformation surfaces that represent the later Pleistocene.

The readjustments of crustal blocks that followed the main deformation took place for the most part along normal faults and were presumably most rapid at first, gradually becoming less and less active. It seems probable that the main part of the differential readjustment, like the main part of the compressive deformation, was accomplished in a comparatively short period. In many places in southern California an old postdeformation geomorphic surface was developed, and except in some zones of late activity, as along the present coast, comparatively little subsequent faulting or folding has taken place. The clearly defined remnants of such a surface are to be seen along the valley of the Santa Clara River in Ventura County.

After the mid-Pleistocene readjustment was over, the sea seems to have retreated from the west border of the continent.

The alluvium carrying the famous Rancho La Brea fauna was probably deposited during the last interglacial period.

The last glaciation saw the ocean near the outer edge of the continental shelf, cutting terraces that are now submerged.

The final stages of the ice retreat are correlated with a minor transgression of the ocean upon the continental border. Of the postglacial geologic history of California we know only that the ocean returned to approximately its present level, that it may have risen slightly for a brief time during the deposition of some young, low alluvial terraces, and afterward subsided, and that the time since the return of the ocean to the low-level stage has sufficed to develop a mature shore line along the drowned coast.

EXCURSION TO THE SAN ANDREAS FAULT AND CAJON PASS

By Levi F. Noble

SAN BERNARDINO PLAIN

The city of Colton lies just north of the Santa Ana River, in the southern part of an alluvium-filled lowland known as the San Bernardino Plain. (See pl. 3.) This lowland is bordered on the north and east by the high San Gabriel and San Bernardino Mountains, composed of pre-Tertiary crystalline rocks, and on the south by hills of similar rocks, but on the west it is continuous with a series of alluvium-filled lowlands that extend toward the Pacific. The surface of these lowlands is made up of broad coalescing alluvial fans built out from the mountains on the north and sloping gently southward to the Santa Ana River. Although the altitude of the San Bernardino Plain at Colton, near its lowest point, is about 1,000 feet (305 meters), parts of the crystalline rock floor beneath the alluvial filling are known from well borings to lie below sea level. The major topographic relief of the region is directly the result of crustal movements that have taken place since late Tertiary time. The lowlands are depressed areas, and the mountains are uplifted areas. The boundaries between them are dissected fault scarps.

CAJON PASS

The San Gabriel and San Bernardino Mountains are parts of a general mountain range which trends eastward across southern California, contains the highest mountain peaks in this part of the State, and forms a rugged barrier between the desert and the coastal region. Opposite the San Bernardino Plain this mountain barrier is broken by a wide gap or depression that extends northwestward diagonally across the axis of the range to the Mohave Desert. The gap is occupied and drained by Cajon Creek and its tributaries and is known as Cajon Pass.

It is followed by the Atchison, Topeka & Santa Fe Railway, the Union Pacific Railroad, the National Old Trails Highway, and the direct air-mail line from Los Angeles to New York and is the principal gateway into the populous coastal region. Cajon Pass follows in a general way fault lines along which great movements have taken place since late Tertiary time. Partly in consequence of these fault movements and partly in consequence of downwarp the pass is occupied by sedimentary beds of Tertiary age. The weakness of these rocks under erosion as contrasted with the resistance of the crystalline rocks of the bordering areas has enabled Cajon Creek to excavate the pass.

SAN ANDREAS FAULT

The most noted active fault in California, the San Andreas rift (see pls. 4, 5), lies along the base of the San Bernardino Mountains and runs northwestward through the lower part of Cajon Pass, where it constitutes the principal structural line with which the pass is associated. This fault, which is the line of seismic disturbance upon which the San Francisco earthquake of 1906 took place, is traceable for nearly 600 miles (966 kilometers) in a southeasterly direction from a point north of San Francisco to a point in the Salton Basin 120 miles (193 kilometers) south of Cajon Pass. It is marked by a curiously straight and almost continuously traceable chain of scarps, ridges, and trough-like depressions, most of which involve Quaternary alluvial deposits and thus afford clear and unmistakable evidence of recent earth movements. This line of recent topographic features upon the San Andreas fault is commonly referred to as the fault trace. Bordering the fault is a belt of roughly parallel branching and interlacing fractures which at some places attains a width of several miles. This belt, the San Andreas fault zone, is a mosaic of elongated sliverlike blocks or wedges whose longer axes trend parallel with the main fault, so that the dominant structure is a sort of slicing, but at many places the rock masses are so intricately shattered and different formations are so mixed together that it is impossible to map them or to determine their relations and age.

The profound difference in the rocks on opposite sides of the San Andreas fault shows that the fault movements have been of great magnitude. Although the nature of the movements is not entirely clear, they were evidently the product of compressive forces that produced a great shear zone along which the movements appear to have been partly horizontal and partly vertical. The fault is a very old line of weakness, upon which movements have recurred through Tertiary and Quaternary

time and perhaps through much of pre-Tertiary time. The movements are still in progress.

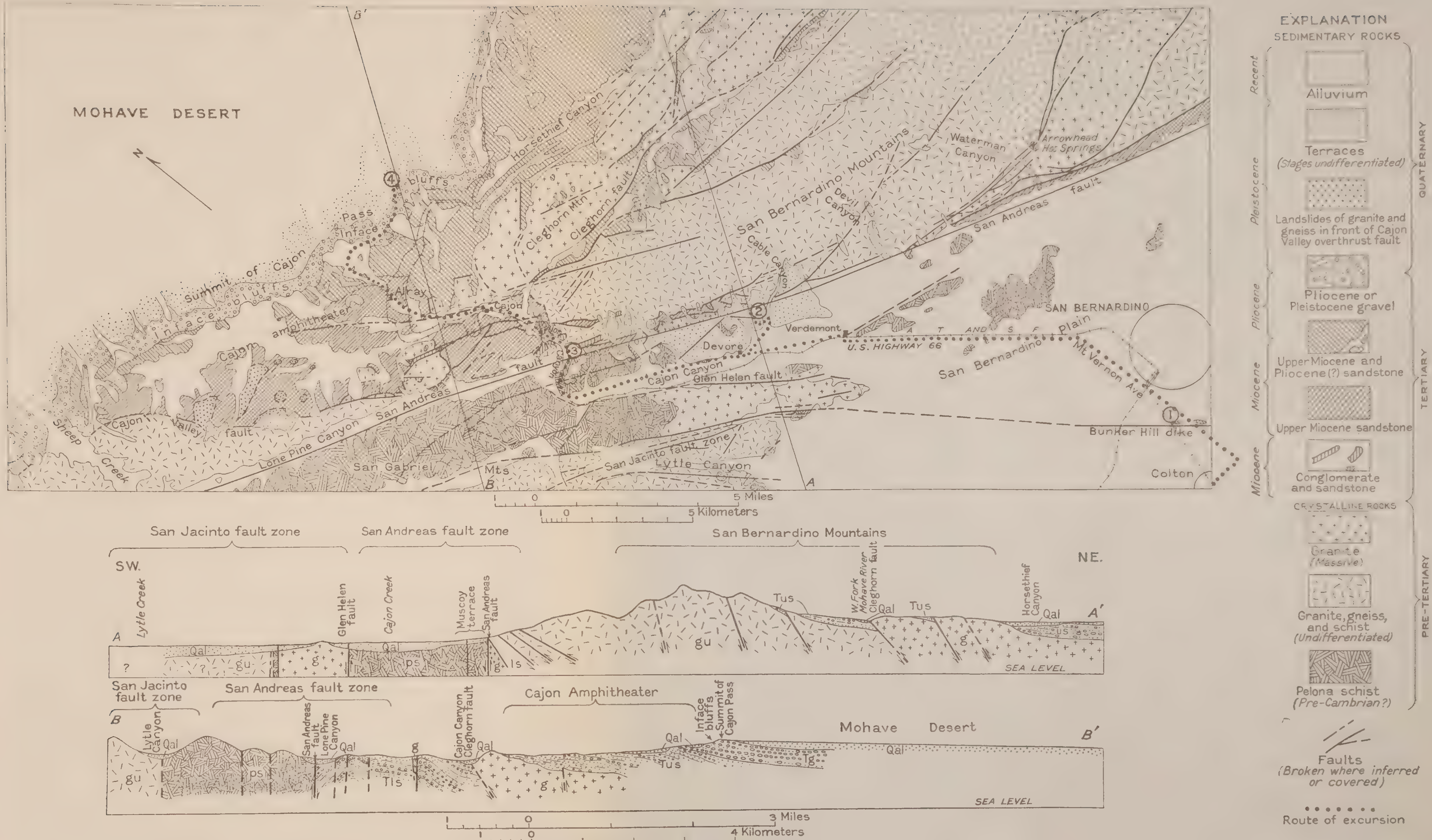
Nowhere in the 30-mile (48-kilometer) sector of the San Andreas fault shown on Plate 3 are the rocks on opposite sides of the fault similar. Only one rock formation, the Pelona schist, lies against the fault on the south. This formation is composed chiefly of bluish-gray quartz-sericite-albite schist but includes beds of chlorite schist, actinolite schist, greenstone, quartzite, and limestone. The schists are cut by masses of Mesozoic granite and by dikes of acidic porphyry and are largely of sedimentary origin but are thoroughly recrystallized. Aside from the fact that they are pre-Tertiary, their age is not known but is believed to be pre-Cambrian. The rocks north of the fault are exceedingly diverse in character, age, and structure. They comprise a number of Tertiary sedimentary formations and a complex assemblage of pre-Tertiary crystalline rocks of different ages. The pre-Tertiary rocks include bodies of massive granite, banded and contorted gneisses, and inclusions of limestone. The granite cuts all the other types of rock and is of Mesozoic age. Some of the limestone inclusions are Paleozoic. Some of the gneisses may be Mesozoic, others Paleozoic or pre-Cambrian. The complex just described forms the greater part of the San Bernardino and San Gabriel mountain masses.

The Tertiary formations occupy a narrow belt of elongated outcrops in the San Andreas fault zone along the base of the San Bernardino Mountains. At Cajon Creek the belt widens out and extends through Cajon Pass to the Mohave Desert.

The oldest Tertiary formation is of lower Miocene age (Vaqueros formation). This is the only Tertiary marine formation exposed in the area covered by the excursion, and it crops out only in small faulted masses of complex structure in and near the San Andreas fault zone at Cajon Creek. (See pl. 3.) Here it rests on the granite. At the base is a very coarse conglomerate of rounded boulders. This is overlain by brown sandstone and shale in which Turritellas and other marine fossils have been found.

The higher Tertiary formations are nonmarine and of more widespread distribution in this area. These are (1) a sandstone of upper Miocene age; (2) a sandstone that is upper Miocene at the base but possibly includes also beds of Pliocene age; and (3) gravel which may range from Pliocene to early Pleistocene in age.

The older sandstone covers an area of several square miles in Cajon Amphitheater. (See pl. 3.) It consists chiefly of arkose sandstone and conglomerate but includes beds of shale and algal limestone. The prevailing color is pale buff, but some beds are



GEOLOGIC MAP AND SECTIONS OF THE REGION ABOUT CAJON PASS

Numbers indicate stopping places. Qal, Recent alluvium; gu, undifferentiated granite, gneiss, and schist; g, massive granite; ps, Pelona schist; Tls or ls, upper Miocene sandstone; Tus or us, upper Miocene and Pliocene (?) sandstone; Tg, Pliocene or Pleistocene gravel. Faults whose direction of dip is unknown are represented as vertical in the cross sections.

PLATES 4 AND 5

PLATE 4

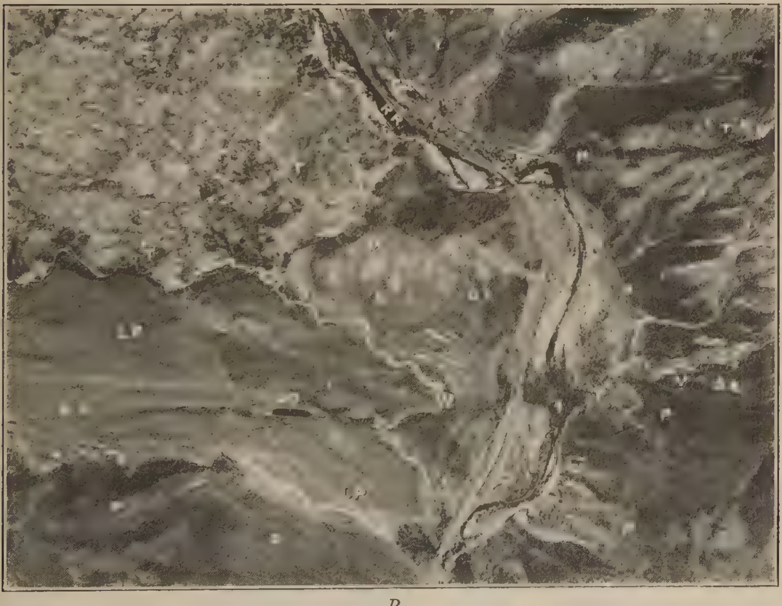
A. AIRPLANE VIEW SHOWING FEATURES ALONG SAN ANDREAS FAULT TO BE SEEN ON DETOUR TO MUSCOY TERRACE

Shows Muscoy terrace and the alluvial fan of Cable Creek dislocated by the fault. C, Cable Creek; CT, Cable Creek terrace (alluvial fan); Z, San Andreas fault zone along San Bernardino Mountain front—ribbons of Tertiary sediments and of pre-Tertiary granite and gneiss along reverse faults which dip toward the mountain mass; SA, San Andreas fault; V, viewpoint at San Andreas fault; D, route of detour; B, minor branch fault which dislocates the alluvium of Muscoy terrace; MT, Muscoy terrace. Top of photograph is approximately northeast.

B. AIRPLANE VIEW SHOWING FEATURES ALONG SAN ANDREAS FAULT IN THE VICINITY OF CAJON CREEK

Note dark area (vegetation) due to rise of water at the fault where the fault crosses Cajon Creek. H, National Old Trails Highway; T, folded and faulted Miocene beds north of San Andreas fault; G, granite, gneiss, etc.; CD, Cozy Dell; RR, Atchison, Topeka & Santa Fe Railway; R, forest ranger station; M, Martinez sandstone (Eocene); C, Cajon Creek; LP, alluvial filling of Lone Pine Canyon; SA, San Andreas fault; PO, sag pond in Lone Pine Canyon; O, stream course offset horizontally at San Andreas fault; V, viewpoint near sag pond; P, Pelona schist south of San Andreas fault; BC, "Blue Cut" on highway. Top of photograph is approximately northeast.

A



B

AIRPLANE VIEWS ALONG SAN ANDREAS RIFT

Photographs by Spence Airplane Photos, Los Angeles,

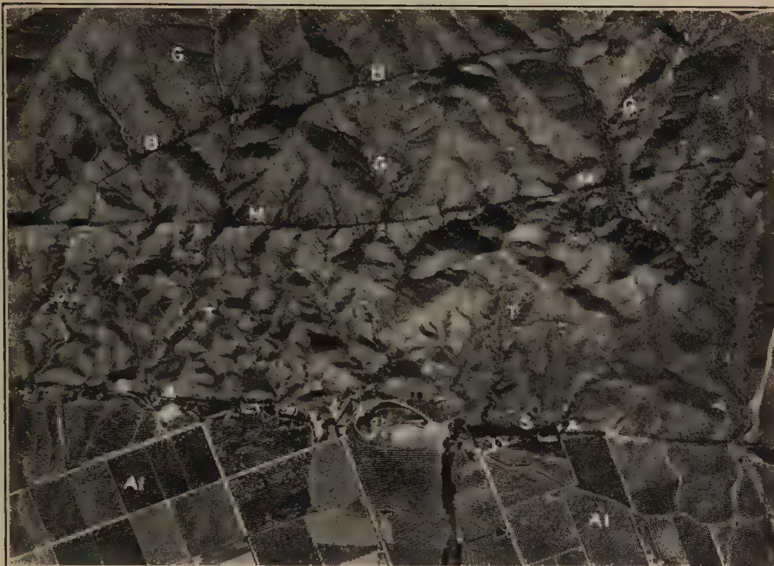
PLATE 5

A. AIRPLANE VIEW SHOWING SAN ANDREAS FAULT ALONG THE SAN BERNARDINO MOUNTAIN FRONT JUST WEST OF CITY CREEK

G, Granite and gneiss; B, branch of the Mission Creek fault; M, Mission Creek fault (a branch of the San Andreas); T, Tertiary beds; SA, San Andreas fault; Al, alluvial filling of the San Bernardino Valley. Top of photograph is approximately northeast.

B. AIRPLANE VIEW SHOWING SAN ANDREAS FAULT AT SOUTHEAST END OF INDIO HILLS, COACHELLA VALLEY

The San Andreas fault runs across the lower part of the photograph. The hills on both sides of the fault are composed of upturned folded and faulted Tertiary beds, whose structure is clearly shown. The smooth areas crossed by the fault are alluvial fans that slope toward Coachella Valley. The fans are cut sharply by the fault. Top of photograph is approximately northeast.



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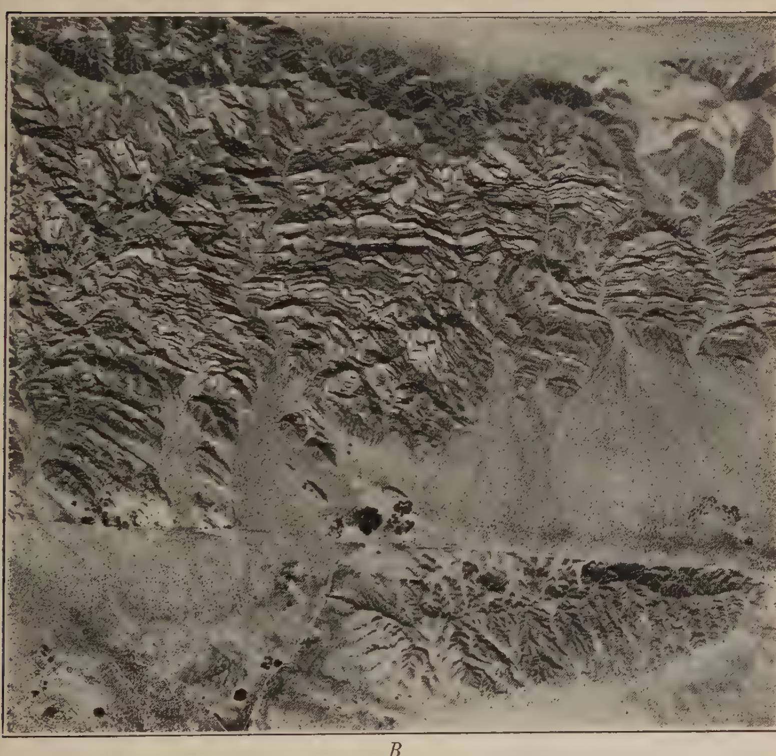

B

AIRPLANE VIEWS ALONG SAN ANDREAS RIFT

Photographs by Spence Airplane Photos, Los Angeles.

red, green, and brown. The formation as a whole is typical of many similar land-laid Tertiary formations found in the desert region. Vertebrate remains of upper Miocene age have been found in its upper part.

The second of these nonmarine Tertiary formations is exposed chiefly in the neighborhood of Horsethief Canyon and is about 1,200 feet (366 meters) thick where crossed by the highway. Like the older sandstone, it consists of arkose sand, gravel, and clay, but the beds are in general poorly consolidated. This formation lies unconformably across both granite and upturned beds of the older sandstone. At most places the younger beds dip northward toward the Mohave Desert, but at some places they are considerably disturbed. (See sections A and B, pl. 3.) Vertebrate remains have been found in the basal beds at a locality where they rest upon granite. Although these beds are separated from the older sandstone by an angular unconformity, the fauna in the basal beds indicates an upper Miocene age not greatly different from that indicated by the remains found in the underlying beds, demonstrating the vigor of tectonic activity along the San Andreas fault even in Miocene time.

The overlying gravel forms a long southward-facing escarpment known as the Inface Bluffs. (See pl. 3.) No exposures of its contact with the underlying younger upper Miocene sandstone have been found, but the contact does not appear to represent an angular unconformity. The gravel, however, marks a change in character of material, for it is composed of cobbles obviously derived from the San Gabriel Mountains, to the southwest, whereas the underlying sandstone contains many cobbles derived from rocks that are exposed only in the desert to the north and in the San Bernardino Mountains to the east. Moreover, the gravel is coarse, whereas the underlying formation consists for the most part of rather fine to medium textured material. The deposition of the gravel marks the first major uplift of the San Gabriel Mountain mass. The age of the gravel is not definitely known. It is possibly late Pliocene or early Pleistocene. The gravel is 800 feet (244 meters) thick where crossed by the highway.

ITINERARY

The trip starts at Colton (altitude 978 feet, or 298 meters). After leaving the Southern Pacific Railroad station the party will proceed eastward to Mount Vernon Avenue and thence northward on Mount Vernon Avenue.

121404—32——3

1.2 (1.9).[2] Cross Colton Avenue (altitude 1,000 feet, or 305 meters). The low escarpment that appears on the right is part of a narrow ridge that runs several miles northwestward across the San Bernardino Plain and is known as the Bunker Hill dike. This ridge is composed of upturned beds of sandy clay and gravel older than the recent alluvial surface material of the plain and represents a partly buried fold or arch upon the line of one of the active faults of the region, the San Jacinto fault. The dike acts as a barrier behind which the subsurface waters percolating southwestward through the alluvium of the plain are ponded. In places behind the dike the waters rise to the surface and make swampy areas. The San Jacinto is perhaps the principal branch of the San Andreas fault, from which it diverges northwest of Colton.

2.1 (3.4). [1][3] Road crosses axis of Bunker Hill dike. The ridge at the left contains exposures of the upturned beds in the dike. A stop on this ridge will afford a view of the major geographic features described in the introduction—the San Bernardino and San Gabriel Mountains, Cajon Pass, and the San Bernardino Plain.

5.7 (9.2). Intersection of Mount Vernon and Highland Avenues (altitude 1,200 feet, or 366 meters). The party proceeds northwestward upon the National Old Trails Highway (United States highway 66) toward Cajon Pass, which is the broad gap in the mountains far ahead. The highway is now upon the alluvial fan of Cajon Creek and ascends the gradual slope of the fan into Cajon Canyon. The San Gabriel Mountains are in view on the left, the San Bernardino Mountains on the right. The hills projecting above the alluvium on the right are composed of Pelona schist. The San Andreas fault lies at the base of the San Bernardino Mountain slope beyond these hills.

12.9 (20.8). Detour to San Andreas fault. (See pl. 4, *A*.) From the highway the route turns north up the wash of Cable Creek. The broad sloping terrace at the right is known as the Cable Canyon terrace and is part of an old dissected alluvial fan whose apex lies in the embayment in the mountain front occupied by Cable Creek. The similar terrace at the left is known as the Muscoy terrace and is a part of the same fan.

A southward-facing escarpment that runs across the Cable Canyon terrace just back of a line of eucalyptus trees marks

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[2] Figures indicate distance from Colton in miles, with kilometers in parentheses.

[3] Numbers in brackets refer to Plate 3.

the San Andreas fault. The fan surface between the San Andreas fault and a parallel fault north of it has been heaved up and tilted backward toward the mountain front. The feature may be observed in profile after the ascent of the Muscoy terrace is begun.

[2] The viewpoint at the San Andreas fault is 2,450 feet (747 meters) above sea level. The tree-filled depression in the foreground, trending northwestward parallel to the mountain face, marks the position of the fault. The ground between the fault and the mountain base has sunk, leaving the Muscoy terrace terminated headward by a scarp 50 to 80 feet (15 to 24 meters) high facing the mountain front, which stands some 500 feet (152 meters) distant. The depression between the scarp and the mountain front is filled by recent boulder gravel poured out from the ravines in the mountain front, and these gravel deposits surround the uplifted and dissected Muscoy terrace.

The San Andreas fault trace is in view northwestward for half a mile (0.8 kilometer) and is easily discernible by the line of dense vegetation along it. The vegetation owes its existence to the rise of ground water at the fault, a characteristic feature at many other places. The view illustrates another feature characteristic of the fault—namely, the abrupt change from place to place in the recent topographic features that constitute the fault trace. At this point the fault trace is a 50-foot (15-meter) scarp facing north. Farther northwest, near the old house, this scarp changes to a narrow sink, or cleft, 50 feet (15 meters) deep. Farther on the cleft gives way to a low scarp facing north, and this changes within a short distance to a low scarp facing south. Then follows a cleft which persists to the col or gap visible between a long mesalike hill and the mountain front. Cross section A, Plate 3, is constructed through the viewpoint. As indicated in the section, the mountain face opposite the Muscoy terrace is an eroded fault scarp in which a number of reverse faults dipping under the mountain mass emerge at different angles. This structure gives rise to a complex fault zone in which narrow slices of decayed granite and of reddish upper Miocene sandstone lie along the lower part of the scarp and dip under the pre-Tertiary crystalline rocks of the mountain mass. Southwestward across Cajon Canyon directly over Devore station an embayment of alluvium with cultivated fields extends into low hills. Across these fields a thin line of trees is visible passing near a large barn. The trees mark a 25-foot (7.6-meter)

northward-facing scarp in the alluvium. This scarp is a recent topographic feature along the Glen Helen fault, which coincides with the south side of Cajon Canyon. The route is retraced to the highway.

13.5 (21.7). Devore filling station at right. Beyond Devore the highway skirts gravel bluffs cut by Cajon Creek in the lower edge of a broad sloping terrace similar to the Muscoy and Cable Canyon terraces. The middle of the terrace is dislocated by a recent fault, the Peters fault, whose scarp faces the mountain front and is therefore not visible from the highway. The San Andreas fault lies along the upper edge of this terrace at the base of the mountain slope, 700 feet (213 meters) higher than Cajon Creek. Several ravines descending the mountain slope have been offset laterally at the fault.

15.4 (24.8). The sloping terrace gives way to hills of Pelona schist capped by Pleistocene gravel older than the alluvium of the terrace.

16 (25.7). The highway crosses a large wash cut through the schist hills. Directly across Cajon Canyon recent topographic features are visible upon the Glen Helen fault. One of these features is a scarp across a talus cone; another, a little farther west, is a fault saddle behind a schist butte.

18.1 (29.1). Highway enters Blue Cut (altitude 2,600 feet, or 792 meters). At this point Cajon Creek bends sharply to the right, the alluvial filling ends, and the stream flows upon bedrock in a narrow gorge cut in Pelona schist. The road cut affords an excellent section across part of the San Andreas fault zone. The steeply dipping beds of schist are cut by numerous faults parallel to the San Andreas, and narrow bands of crushed greenstone and gneiss are mingled with the schist by the faulting. As the highway approaches the San Andreas fault the schist becomes so intricately crushed that it is virtually gouge.

19.2 (31). [3] The highway crosses the San Andreas fault at the end of the cut. Dense vegetation and swampy ground mark the course of the fault across Cajon Creek. Here the schist south of the fault has been raised in a low scarp facing upstream. The creek gravel is banked against this schist barrier, which acts as a submerged dam and forces to the surface the waters percolating downstream in the gravel. The fault trace appears in the bluff at the right of the highway, where a vertical fault of some 15 feet (4.5 meters) may be seen in cross section. The fault displaces Quaternary alluvial material and is one of several parallel faults that drop the ground to the north. Farther southeast, beyond the bluff,

a sag pond marks the fault trace. From a point near this sag pond (see pl. 4, *B*) the San Andreas fault is in view for over 10 miles (16 kilometers) northwestward in Lone Pine Canyon, an alluvium-filled valley which coincides with the fault and is an excellent example of the longitudinal valleys characteristic of the fault zone. The ridge on the south side of the canyon is composed of Pelona schist and represents a dissected block arched down northward to the San Andreas fault. The rocks in the ridge on the right (north) side of the canyon for several miles beyond Cajon Creek are Tertiary beds of exceedingly complex structure; beyond the Tertiary beds the ridge is composed of granite to the head of the canyon. The granite ridge, like the schist ridge south of the canyon, is one of the long, narrow, even-crested fault blocks typical of the San Andreas fault zone. It is bounded on the north by the Cajon Valley thrust fault (see pl. 3), which separates the granite from Tertiary beds in Cajon Valley north of the ridge. The fault plane dips south under the granite ridge, so that the pre-Tertiary granite overrides the Tertiary sediments and the ridge is structurally an inverted granite prism with the apex pointing downward.

The alluvial filling of Lone Pine Canyon exhibits recent fault features such as scarps, ridges, and sag ponds on the line of the San Andreas fault. Many of these features are visible from the viewpoint. Near the mouth of the canyon a stream course across the fault is offset laterally several hundred feet at the fault trace, thus affording evidence of recent horizontal movement, the ground south of the fault having been shifted northwestward in relation to the ground north of the fault. (See pl. 4, *B*.) The sharp bend in Cajon Canyon at the Blue Cut is a feature that, taken in connection with the offset of other stream courses southeast of Cajon Creek, is believed to be the result of older horizontal movements aggregating about a mile (1.6 kilometers).

The hill directly across Cajon Creek at the mouth of Lone Pine Canyon is part of one of the granite wedges in the San Andreas fault zone. It is capped by beds of lower Miocene age that rest unconformably upon the granite. Upper Miocene beds lie immediately against the north side of the San Andreas fault at the point where the party stands but are buried under alluvium. Here, as elsewhere near the fault, the rock structure is exceedingly complex, sliverlike wedges of granite alternating with similar wedges of Tertiary beds.

19.6 (31.5). Outcrop of lower Miocene beds (see p. 12) in cut at right of highway. The unconformity between the lower

Miocene conglomerate and the underlying gneiss is well exposed here.

19.9 (32). Forest-ranger station on left; bluffs of dissected terrace gravel on right. Thence onward to Cajon station an upper Miocene sandstone (see pp. 12, 13) is exposed on both sides of the highway. The best exposures are visible on the left (west) side of the canyon, where the sandstone covers an area of several square miles, the more indurated beds cropping out conspicuously in bold ledges. The beds are cut by numerous faults, and are bent into folds whose axes trend west and meet the San Andreas fault at a low angle—a structure suggestive of horizontal drag along the fault. Along the base of the mountain slopes at the right the sandstone is faulted against the granitic rocks of the San Bernardino Mountains. The fault is a reverse fault that dips eastward under the granite.

20.8 (33.5). Highway bends to the left, following Cajon Creek. The high granite scarp at the right marks a fault which runs far eastward into the San Bernardino Mountains and is designated the Cleghorn fault. (See pl. 3.) The fault here separates the upper Miocene sandstone from granite, and the plane is not exposed, but farther east the fault is a reverse fault whose plane dips steeply north. An outcrop of sandstone lying against the fault may be seen at the base of the granite scarp. Upon the granite surface at the top of the scarp lie beds of a younger upper Miocene sandstone. (See pp. 12, 13.)

21.6 (34.8). Cajon station at left. The road now follows the base of the granite scarp. After passing Camp Cajon, the younger upper Miocene sandstone lying on granite can be seen at the right of the highway.

22.9 (36.8). Road to Los Angeles County Park comes into the highway at the left, at an altitude of 3,150 feet (960 meters). Structure section B (pl. 3) crosses the highway at this point. The high granite hill on the left (west) side of Cajon Canyon is entirely surrounded by the older upper Miocene sandstone and is bounded by faults. At one point high on the hill remains of a whale have been found in a tiny outcrop of lower Miocene sandstone resting upon the granite. The remains are associated with Turritellas and clams. Picturesque ledges of upturned sandstone are visible in Cajon Valley to the right of the granite hill. The highway now leaves Cajon Creek and ascends an alluvium-filled valley leading toward the summit of Cajon Pass. The rocks on both sides of the valley are the earlier upper Miocene sandstone.

23.5 (37.8). Highway crosses southbound track of railroad.

24.3 (39.1). Highway crosses northbound track of railroad at Alray station. The younger upper Miocene beds here unconformably overlie the older upper Miocene sandstone in the ridge at the right. The highway crosses the contact a short distance beyond Alray, but the contact is buried beneath alluvium.

24.9 (40.1). Younger upper Miocene beds exposed in cuts at right. The highway is now approaching a line of gravel bluffs whose top on the sky line ahead is the summit of Cajon Pass and the rim of the Mohave Desert. These bluffs form a southward-facing escarpment many miles in length, which here drops into the great amphitheater excavated by Cajon Creek and its tributaries but which farther northwest directly faces the rocky slopes of the San Gabriel Mountains. The entire long escarpment has been designated the Inface Bluffs.

25.9 (41.7). Highway curves eastward, climbing diagonally up the Inface Bluffs. Thence onward to the summit of Cajon Pass the Pliocene or Pleistocene gravel (pp. 12, 13) is magnificently exposed in the highway cuts. Here, as at most other places in the bluffs, the gravel dips 25°–30° N., but the dip rapidly becomes less steep north of the bluffs, which thus coincide with a zone of maximum tilting.

27.9 (44.9). Near the summit of Cajon Pass exposures of brown Quaternary alluvium appear in a cut at the left of the highway. The alluvium overlies the gravel of the bluffs and represents an abrupt change in character of material. The alluvium is composed almost entirely of fragments of Pelona schist, whereas the gravel contains very little schist; the alluvium consists of angular material, whereas the cobbles in the gravel are rounded. Inasmuch as no Pelona schist is exposed anywhere north of the San Andreas fault, it is evident that the alluvial material can have come only from the schist ridges south of the fault, and it is equally evident that this material was deposited before the Cajon Amphitheater south of the Inface Bluffs was excavated, for the amphitheater lies between the material and its source. The abrupt appearance of this alluvial material, obviously derived from a localized area in the San Andreas fault zone, affords striking evidence of one of the recurrences of movement along the San Andreas fault.

27.7 (44.6). The summit of Cajon Pass is reached at an altitude of 4,300 feet (1,311 meters). The broad plain that slopes far northeastward into the Mohave Desert is floored by Quaternary alluvium and represents an old detrital slope that once

extended continuously to the base of the San Gabriel Mountains but has been beheaded by the Cajon Amphitheater. Many ravines cut in the upper part of the slope are truncated headward at the rim of the amphitheater. The alluvium seemingly constitutes a relatively thin veneer spread out over an old desert piedmont slope, or "pediment," for at one place several miles northeast of the summit a monocline in the underlying beds is beveled by the alluvium, which is there not over 100 feet (30 meters) thick.

[4] The chief features of the view from the summit are the broad alluvial desert slope stretching away to the northeast from the Inface Bluffs, upon which the party stands; the San Bernardino Mountains, to the east; the amphitheater of Cajon Creek, to the south; and the long parallel ridges marking the San Andreas fault zone, to the southwest, with the high disordered San Gabriel Mountain mass rising beyond the even-crested ridges of the fault zone. Cross section B (pl. 3) will aid in interpreting the structural features in view.

The Inface Bluffs are visible southeastward to the point where the railroad grade crosses them. The long level surface at the right of the railroad grade is the truncated floor of a wide old alluvium-filled valley that formerly reached across the site of the Cajon Amphitheater to the San Gabriel Mountains; the valley probably carried one of the chief tributaries of the Mohave River, which now receives drainage only from the San Bernardino Mountains. After the valley was cut it was filled to a depth of 100 feet (30 meters) or more by an alluvial deposit made of fragments of Pelona schist derived from the ridges south of the San Andreas fault. The valley was then truncated by headwater erosion of Cajon Creek.

Beyond the terrace rises a granite mountain known as Cleghorn Mountain, which is a part of the extreme west end of the San Bernardino Range. Upon the sloping surfaces of the mountain lie remnants of basal beds of the younger upper Miocene formation, the beds everywhere dipping parallel with the granite slopes upon which they lie. The slopes are therefore exhumed surfaces of erosion, and their attitude is an index of the mountain structure. The long slope by which Cleghorn Mountain descends westward to Cajon Creek is one of these surfaces and represents a downwarp of the west end of the San Bernardino

Mountains to Cajon Pass. Cleghorn Mountain is an asymmetric bulge or arch raised on the south along the Cleghorn fault and tilted westward to Cajon Pass and northward to the Mohave Desert. Its structure is typical of all the western part of the San Bernardino Mountain mass in view toward the east, essentially a succession of crustal blocks, each of which is tilted north and is raised on the south along a northward-dipping reverse fault. (See section A, pl. 3.) The mass as a whole was raised by compression. Inasmuch as it is composed of massive crystalline rocks the deformation has resulted in reverse faults, shearing, arching, and tilting. If it had been composed of sedimentary rocks the same deformation would have resulted in folding and thrusting.

Other evidence of arching in the region is plainly visible in the parallel ridges of the San Andreas fault zone, whose even crests descend steadily for many miles to the lower canyon of Cajon Creek and the San Bernardino Plain.

ASPHALT DEPOSITS AND QUATERNARY LIFE OF RANCHO LA BREA

By Chester Stock

The name Rancho La Brea was applied originally to a Mexican land grant in the vicinity of Los Angeles, but as now generally understood it refers to an area of approximately 32 acres (13 hectares) on Wilshire Boulevard a few miles west of the heart of the city. The unique paleontologic features of this locality were first fully appreciated a quarter of a century or more ago.

The asphalt beds, which have resulted from a penetration and exudation of oil, form part of a terrestrial accumulation of clay, sand, and rubble. These superficial deposits retain a horizontal position, are several hundred feet in maximum thickness, and rest upon an eroded surface formed on folded and presumably faulted marine strata of Tertiary and Pleistocene age, elsewhere exposed in the Los Angeles Basin. Structural features facilitated an upward movement of petroliferous material from the oil sands of the older rocks, and the outpours or seeps occurred concomitantly with the deposition of the superjacent formation. Minor quantities of gas and oil still reach the surface, but the activity of the seeps has diminished considerably, even in historic time.

Excavations by the Los Angeles Museum have shown that the fossiliferous asphalt of the Pleistocene outpours varies con-

siderably in lateral and vertical extent. The masses lie close to the present surface and extend downward to a depth of 15 to 35 feet (4.5 to 10.6 meters). Not only did the outpours accumulate in the hollows of an irregular land surface, but some exudations were accompanied perhaps by sufficient force to form craterlike depressions into which the tar and oil subsequently flowed.

The trapping of rodents and birds by seeps occurring to-day presents in a graphic way the method by which the larger outpours of the Pleistocene caught the animals and plants of that time. Accumulating in a region where life abounded, the tar pools doubtless frequently entrapped creatures who in their movements through this region unwittingly came into contact with the sticky mass. More than 100 species of plants and animals have been described from these deposits.

The cries and struggles of a mired animal doubtless lured other creatures to the traps, and among those frequently caught were the flesh eaters. That the carnivores often succumbed is clearly manifested by the fossil record. A census of the mammals indicates that over 90 per cent belong to predatory groups. A similar preponderance of predators is revealed by a census of the fossil birds. Among the mammals the more frequent captives were the saber-tooth (*Smilodon californicus*) and the dire wolf (*Aenocyon dirus*), both of which are represented by many hundreds of skulls and by thousands of skeletal elements. Also included in the assemblage are the great lionlike cat (*Felis atrox*), the coyote (*Canis ochropus orcutti*), and the short-faced bear (*Tremarctotherium californicum*). Among the characteristic herbivores are the mammoth (*Archidiskodon imperator*), mastodon (*Mammut americanum*), horse (*Equus occidentalis*), bison (*Bison antiquus*), camel (*Camelops hesternus*), antelope (*Capromeryx minor*), and several kinds of ground sloths (*Mylodon harlani*, *Nothrotherium shastense*, and *Megalonyx jeffersonii*).

Birds are likewise well represented, and the assemblage as a whole is more varied than the mammalian group. Among these the falconlike birds constitute the dominant division, including the largest bird of flight, a condorlike vulture (*Teratornis merriami*), and great numbers of condors, vultures, eagles, and hawks. Next to the Falconiformes the largest group are the gallinaceous birds, of which the principal representative is a turkey (*Parapavo californicus*).

The animals specifically mentioned above are extinct, but the fauna includes also living species. Many mammals and birds of the Rancho La Brea fauna are identical with or closely related to species found elsewhere in North American Pleistocene deposits. The faunal stage represented by the collections

obtained in the larger excavations conducted by the Los Angeles Museum appears to be a homogeneous one, dating probably from some period within the last half of the Pleistocene. Certain pits or excavations, notably pit 10, have yielded material, including human remains, evidently belonging to a later stage.

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GENERAL GEOLOGY OF THE LOS ANGELES BASIN

By H. W. Hoots

The city of Los Angeles lies along the northern border of a broad plain that is flanked on the west and south by the shores of the Pacific and on the north, northeast, and east by ranges of hills and mountains. At the southwest corner of this plain a prominent topographic feature known as the San Pedro Hills projects into the ocean and appears to protect by its resistant rocks much of the plain from destruction by marine abrasion. From the accompanying map (pl. 6) it is apparent that this low plain, though not completely surrounded by high areas, has some of the characteristics of a topographic basin. Geologically this basin, commonly called the Los Angeles Basin, is a broad syncline that, beneath its surface veneer of alluvium, contains as its upper strata 5,000 to 10,000 feet (1,500 to 3,000 meters) of marine Pliocene and Pleistocene rocks and is bordered by elevated and intricately folded and faulted areas of rocks ranging in age from Triassic to Pliocene that have an aggregate thickness of 25,000 to 40,000 feet (7,600 to 12,200 meters). These adjoining upland areas received most of their present elevation as a result of crustal movements during the Quaternary period—movements so recent that hills and mountains still retain remnants of old geomorphic surfaces that were carved during late Pliocene and Pleistocene time, when these areas were much lower with reference to the sea.

The Los Angeles Basin is not a simple syncline; it is crossed by northwestward-trending lines of anticlinal folding and faulting that have transformed this broad basin into a geosyncline. (See figs. 1, 2.) This deformation also occurred in Quaternary time, and as a result most of these interbasin anticlines and faults are expressed at the surface by elongated low hills of late Pleistocene rocks broken or approximately paralleled

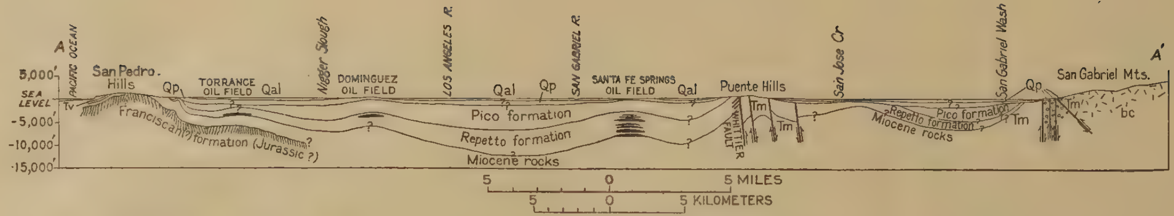


FIGURE 1.—Structure section on line *A–A'*, Plate 6. Qp, Marine terraces, etc. (Pleistocene); Qal, Recent alluvium; Tm, Miocene and Oligocene (?) sediments; bc, "Basement complex" (Jurassic (?) and older)

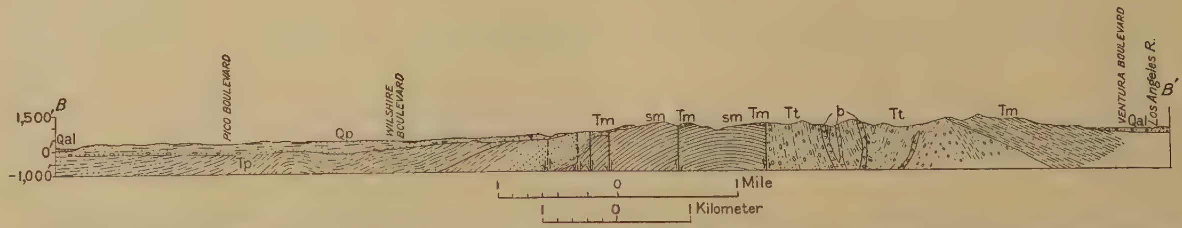


FIGURE 2.—Structure section on line *B–B'*, Plate 6. Qal, Recent; Qp, Pleistocene; Tp, Pliocene; Tm, Modelo formation (upper Miocene); Tt, Topanga formation (middle Miocene); sm, Santa Monica slate (Triassic?); b, basalt (Miocene)

Geologic formations in the Los Angeles Basin

Age		Formation	General character	Thickness		Known distribution
				Feet	Meters	
Quaternary.	Recent.	Alluvium.	Buff sand, clay, and gravel.	0–1,000	0–305	Extensive throughout low areas of Los Angeles Basin.
		—Unconformity				
	Pleistocene.	Terrace deposits, including Palos Verdes sand or "upper San Pedro" of Arnold.	Several ages of marine and stream terrace and alluvial-plain deposits of buff and reddish-brown sand, clay, and gravel; some are either folded or highly elevated.	0–300	0–91	San Pedro Hills, Inglewood oil field, Santa Monica Plain, and mountain valleys.
		—Unconformity				
		San Pedro formation (restricted), ("lower San Pedro" of Arnold).	Light-colored, well-sorted fossiliferous marine sand and coarser, cross-bedded unfossiliferous sand.	400±	122±	In San Pedro and along north flank of San Pedro Hills: also in wells of Los Angeles Basin.
			Silt and fine, poorly sorted sand; mollusks and Foraminifera abundant.	100–200	30–61	
		—Unconformity (?)				
			Calcarenyte, chalk, marl, and lenticular gravel with limestone cobbles; Foraminifera abundant.	5–300	1.5–91	
		—Local unconformity				
Tertiary.	Pliocene.	Pico formation (upper and middle Pliocene).	Light-gray and bluish-gray fine micaceous sandstone, silt, and clay shale; Foraminifera abundant.	1,000–1,500	305–457	Fragmentary sections intermittently at points around borders of the basin from point northwest of Santa Monica eastward to Olive and southward to Newport and Capistrano; north flank of San Pedro Hills.
			—Local unconformity			
			Light-brown and grayish-brown silt, clay, shale, and sandstone; Foraminifera abundant. Absent locally.	1,000–1,500	305–457	
			Light-brown and grayish-brown clay shale, silt, and sandstone; Foraminifera abundant. Absent locally.	400–600	122–183	
		Repetto formation [a] (lower Pliocene).	Light brownish-gray and bluish-gray clay shale, sandstone, and silt; Foraminifera abundant. This formation contains most of the producing oil zones of the Los Angeles Basin.	2,500–5,000	762–1,524	
		—Local unconformity				
	Miocene.	Modelo formation to west; Puente formation to east.	These formations are equivalent in part and consist of hard white and tan, weathering brown and dark gray, platy siliceous shale, clay shale, and white punky diatomaceous shale interbedded with massive units of buff and gray sandstone. Much of shale is highly organic, and all types of shale contain abundant Foraminifera locally.	4,000–7,000	1,219–2,134	San Joaquin Hills, Santa Ana Mountains, Puente Hills, Repetto Hills, San Pedro Hills, Santa Monica Mountains, and beneath Los Angeles Basin.
		—Unconformity				
		Topanga formation.	Coarse brown and gray massive sandstone and conglomerate and dark-gray shale; megascopic fossils (*Turritella ocoyana* fauna) abundant but Foraminifera rare; includes much intrusive and extrusive basalt.	700–7,500	213–2,286	San Joaquin Hills, Santa Ana Mountains, Puente Hills, Santa Monica Mountains, and San Pedro Hills.
		Vaqueros formation.	Coarse brown, gray, and red sandstone and conglomerate with red and green clay; megascopic fossils (*Turritella inezana* fauna) locally abundant.	3,000–4,000	914–1,219	Santa Ana Mountains, San Joaquin Hills, and probably Santa Monica Mountains.
	Oligocene and Eocene.	Sespe formation.	Red and green clay, sandstone, and conglomerate with buff to white sandstone; probably of continental origin in greater part.			Santa Ana and Santa Monica Mountains.
		—Local unconformity				
	Eocene.	Tejon formation.	Coarse buff arkosic sandstone with basal conglomerate; marine megascopic fossils.	500–600	152–183	Northern part of Santa Ana Mountains.
		—Unconformity				
		Martinez formation.	Light-brown and gray sandstone and shale and in Santa Monica Mountains many massive reefs of algal limestone; marine megascopic fossils.	250–900	76–274	Santa Ana and Santa Monica Mountains.
Cretaceous.	Upper Cretaceous.	Chico formation.	Hard massive coarse conglomerate and sandstone with black and blue shale and seams of low-grade coal.	8,000	2,438	Santa Ana and Santa Monica Mountains.
	Lower Cretaceous (?).	Trabuco formation.	Soft coarse red conglomerate and sandstone with matrix of red clay; apparently of continental origin.	300–750	91–229	Santa Ana Mountains; a similar unit occurs in Santa Monica Mountains.
		—Unconformity				
Jurassic (?).		Granitic intrusives.	Granodiorite and granite; exact age in southern California uncertain.			Santa Ana and San Gabriel Mountains and eastern part of Santa Monica Mountains.
		Franciscan formation.	Albitic, amphibolitic, and chloritic schists, quartz schist, quartzite, serpentine, etc. Age unknown; metamorphism in this area suggests that it is older than the granitic intrusives and the Santa Monica slate.	([b])	([b])	Core of San Pedro Hills and beneath westernmost part of Los Angeles Basin.
Triassic (?).		Santa Monica slate.	Dark-gray to black slate, much of which has undergone contact and regional metamorphism to mica schist, phyllite, and spotted slate; similar slate in Santa Ana Mountains contains marine Triassic fossils locally.	5,000–7,000+	1,524–2,134+	In Santa Monica Mountains, where Triassic age is questionable; similar slate in Santa Ana Mountains.

[a] See p. 31 for definition.

[b] Thickness unknown; apparently several thousand feet.

by prominent scarps. Baldwin Hills (Inglewood oil field), Dominguez Hill, and Signal Hill (Long Beach oil field) are anticlinal hills of this class.

The two major lines of anticlinal folding within the Los Angeles Basin are known as the Newport-Inglewood uplift and the Coyote Hills uplift; the former is generally considered to have resulted from movement along a deep-seated fault extending from Newport Beach northwestward across the basin. These two major lines and adjoining ones of lesser magnitude contain 17 oil fields, most of which are on more or less perfectly formed anticlinal folds. Prior to January 1, 1932, these fields had produced about 1,765,000,000 barrels (280,613,000,000 liters) of oil.

The basinward-dipping rocks along the northern and northeastern borders of the Los Angeles Basin are commonly separated from the adjoining upland areas by high-angle faults or fault zones of large displacement. Such fault zones pass along the southern base of the Santa Monica Mountains, through Hollywood and Los Angeles, and along the southern border of the Puente Hills. Oil has been trapped within and just south of these fault zones in Pliocene and Miocene rocks that are flexed into steep basinward-dipping monoclines and minor folds. Surface seepages of oil along the fault zones and along the outcrops of oil sands within the monoclines attracted the attention of old-time prospectors and resulted in oil production as early as about 1880. Five major fields have been discovered along these fault zones and prior to January 1, 1932, had produced about 194,000,000 barrels (30,843,000,000 liters) of oil.

The oil fields in the Los Angeles Basin may be divided into three groups according to the geologic evidence which led to their discovery:

1. Fields with surface seepages of oil. The Los Angeles City, Whittier, and Brea-Olinda fields belong to this group. In these areas oil is produced from fault zones and associated basinward monoclines and minor folds that abut against the faults. Realization of the importance of such structural features as possible controlling factors in oil accumulation has led to the prospecting of many areas of similar structural character throughout California.

2. Fields with surface evidence of comparatively late uplift by anticlinal folding and faulting. Such evidence usually consists of low hills elevated above the alluviated floor of the basin. Fields of this type are found along the Newport-Inglewood and Coyote Hills uplifts and in neighboring areas.

3. One field of anticlinal character without recognizable topographic expression. This field, Playa del Rey, was discovered

by correlating subsurface evidence available from the records of scattered unsuccessful wildcat wells; micropaleontology has proved the most valuable aid to the geologist in making such correlations.

OIL DEVELOPMENT IN THE LOS ANGELES BASIN

By H. W. Hoots

HISTORY

The first commercial production of oil in the Los Angeles Basin was obtained about 1880 from upper Miocene rocks of the Puente field; this area is in the Puente Hills, within the broad Puente fault zone that parallels and lies just north of their southern border. Discovery of other fault-zone fields along the northern border of the basin followed in the next 20 years—the Los Angeles City fields in 1892, Brea-Olinda about 1897, Whittier in 1893, and Salt Lake in 1902. The first field to be found in which anticlinal folding was definitely the major factor controlling oil accumulation was discovered in Pliocene strata at West Coyote in 1908; other fields of similar structural character in more central parts of the basin were located at irregular intervals until on May 1, 1931, 22 fields throughout the basin were producing a total of 302,799 barrels (48,141,464 liters) a day from 3,863 wells (an average of 78 barrels (12,401 liters) to the well), and were estimated to have a potential daily production of 543,330 barrels (86,383,126 liters) (an average of 108 barrels, or 17,175 liters) if the wells were opened to capacity flow. Probably 75 per cent or more of this oil was coming from Pliocene rocks, and the remainder from the Miocene. Several fields, such as Long Beach, Santa Fe Springs, and Huntington Beach, contain from three to eight productive oil and gas zones, the upper of which are of Pliocene and the lower of Miocene age. Although all oil produced prior to 1900 was obtained at depths of less than 2,000 feet (610 meters), many wells drilled since 1928 have been productive below 8,000 feet (2,438 meters); and in May, 1931, one well in the Seal Beach field was producing a small amount of oil from a depth of 9,054 feet (2,759 meters). The initial daily production of the wells has ranged from a few barrels to 10,000 barrels (1,589,000 liters) a day.

Several of the older fields were in May, 1931, practically extinct. The old Puente field yields only 1,900 barrels (302,777 liters) of oil a month from 28 wells, of which about 1,400 barrels comes from one well, and the prospect for profitable production at greater depths is reported to be discouraging; the Los Angeles

Oil fields of the Los Angeles Basin, in order of their discovery [a]

[Compiled by H. W. Hoots with the assistance of Walter J. Crown, of the State Mining Bureau, and Stanley G. Wissler, paleontologist of the Union Oil Co.]

Field	Year of discovery	Geologic structure	Producing oil zones: Name	Producing oil zones: Age	Depth to top of oil zones on top of structure (feet)	Thickness of oil zone (feet)	Gravity of oil (A. P. I.)	Total proved (acres) [b]	Total production to January 1, 1931 (barrels) [c]	Peak production: Barrels	Peak production: Year	Average number of producing wells in December, 1930 [d]	Wells shut in, December, 1930 [d]	Average daily production in December, 1930 [d] (barrels)	Past production per acre (barrels), January 1, 1931
Puente	1880	Faulted monocline		Puente	1,000–2,000		20–32	158	(e)	(e)	(e)	(e)	(e)	(e)	(e)
Los Angeles City	1892	Faulted anticlines and monocline.	Upper Lower	Puente	[f] 475–1,500	50–200 25–100	18–20 12.5–16	1,168	[g] 60,246,583	2,027,000	1902	218	[h] 7	[h] 401	[g] 24,610
Brea-Olinda	1897	Faulted anticlines and monocline against fault.	Upper Middle Lower	Pico-Repetto Puente	Brea 1,200; 2,100; 3,200 Olinda 260–3,600	400 1,000 1,000	16–20 20–24 29–32	1,969	[i] 137,232,682	[i] 7,081,165 7,006,934	1911 1927	358	78	10,821	[i] 64,515
Whittier	1898	Monocline against fault	Upper Middle Lower	Repetto Puente	250–3,500	3,000	14–24	633	14,595,201	1,156,752	1917	172	-------	1,402	23,057
Salt Lake	1902	Anticline, syncline, and monocline, probably faulted.	Upper Arcturus Lower Arcturus Salt Lake	Repetto	650 1,550 3,650	3,000+	14–18 17–19 9–22	1,280	(g)	4,535,800	1908	48	-------	744	(f)
Beverly Hills	1908	Anticlinal dome	Main zone	Repetto	2,450	600	15–22	84	2,848,916	246,223	1912	13	-------	296	34,000
West Coyote	1908	Anticline	First Second Third	Repetto	2,800 3,300 4,200	475± 800±	24 27–30	972	124,216,765	9,706,967	1918	183	44	10,526	127,775
East Coyote	1911	Faulted anticline	Upper Lower Deep	Repetto-Puente	2,450 2,750–2,900 4,000	300 400–600 100	17–20 ------ ------	1,030		3,328,042	1917				
Newport	1906–1910	(?)	Tar zone Oil zone	Puente	800 1,800	150± 150	7–9 16	75±	121,195+?	32,973	1926?	3	-------	13	1,750+?
Montebello	1917	Anticline	First Second Third	Repetto	1,750 2,450 3,550	500 1,000 100±	16.2–23.2 21.4–26 30.2	1,180	86,515,210	12,100,784	1919	184	4	7,227	73,320
Yorba Linda	1918	Asymmetric anticline	Oil zone	Puente	1,900	500–1,100	15–21	65	(k)	(k)	(k)	(k)	(k)	(k)	(k)
Richfield	1919	Faulted anticline	Chapman Kraemer	Puente	2,850 3,700	600 800–900	16–19	1,043	[l] 64,626,541	[l] 8,314,528	1922	[l] 867	260	[l] 8,036	[l] 62,000
Huntington Beach	1920	Distorted monoclines, faulted	Bolsa: Upper Bolsa: Lower Ashton: Upper Ashton: Intermediate Ashton: Lower	Repetto Puente	[f] 2,000–4,900	160 160 170 520 640	14–15.5 18–19.5 19.5–20.5 21.5–24 25–27.5	2,476	173,669,969	34,355,642	1923	444	120	25,900	70,141
Long Beach	1921	Elongated anticline; minor faults.	Alamitos Upper Brown Lower Brown Deep	Repetto Puente	2,300 2,950 3,300 5,000	600 350 1,400 3,000	22.3 25–26 28–29 28–31	1,350	419,777,898	68,810,361	1923	206	124	94,927	310,946
Santa Fe Springs	[m] 1921	Elongated dome	Gas Foix Bell Meyer Nordstrom Buckbee O'Connell Clark Hathaway	Pico Repetto Puente	2,000 3,470 3,650 4,050 4,950 5,520 6,240 6,740 7,205	 80 200 680 450 530 475 300 500	 28–29 30–32 32 34 33 34 33–34 33–34	1,572	305,814,707	79,781,275	1923	506	167	86,933	194,539
Torrance	1922	Eastward anticlinal nose	One zone	Repetto-Modelo	West, 2,700 Central, 3,100 East, 3,550	500 300	12–19 20–27 16–25	3,553	68,352,689	17,526,123	1924	544	31	9.031	19,238
Dominguez	1923	Anticline	Callender	Repetto	3,750	1,500+	26–32	870	45,555,211	13,328,817	1925	53	19	9,923	52,362
Rosecrans	1924	Three closely associated domes.	*Athens area:* Upper Athens Lower Athens Upper Howard Park Lower Howard Park *Central dome:* First Second Third *Main Street dome:* Oil zone	Repetto Repetto	 4,120 4,540 4,740 4,900 3,900 4,650 4,820 3,700	 350 100 90 200 50 100 100 1,000	 35 40–41 36.5 36.5 36–43	402	24,786,718	7,263,466	1925	101	1	6,341	61,658
Inglewood	1924	Faulted anticline	One zone	Pico and Repetto	West of fault, 1,160 East of fault, 1,060	1,700 1,100	13–18 18–29	899	74,460,630	18,348,395	1925	216	-------	15,709	82,826
Seal Beach	1926	Partial anticline and dome, faulted.	Bixby Selover Wasem Upper McGrath Lower McGrath	Repetto Puente	4,300 4,550 4,870 5,920 7,150	170 200–285 950 900 900	22–25 25–28 28–32 28 29–32	440	51,893,508	16,424,929	1927	125	-------	16,675	118,000
Potrero	1927	Faulted anticline	First Second Third	Repetto	3,700 5,420 6,400	146 142 108	45 40 38	112	1,017,665	638,268	1930	14	-------	1,516	9,086
Lawndale	1928	Very small dome, faulted (?)	One zone	Upper Modelo	5,750	125–200	31.5	15?	538,691	392,533	1929	5	-------	325	35,911?
Playa del Rey	1929	Anticline	Upper Lower	Repetto Basal Modelo	3,500 5,500	1,100 0–150	23–24	200+	4,745,102	4,719,981	1930	146	-------	39,989	23,225?

[a] An earlier table compiled by F. P. Vickery and published in the Oil Bulletin, April, 1928, has aided materially in the compilaiton of this table.
[b] Includes previously productive acreage, now abandoned.
[c] 1 barrel = 42 gallons, or 159 liters.
[d] California State Mining Bureau figures.
[e] Included in Brea-Olinda.
[f] Upper and lower limits of producing sands.
[g] Includes Salt Lake field.
[h] Figures for April, 1931.
[i] Includes Puente field.
[j] Included in Los Angeles City.
[k] Included in Richfield.
[l] Includes Yorba Linda field.
[m] Date of first major discovery; first producing well in 1919.

City and Salt Lake fields, responsible for the first periods of overproduction in southern California, have about exhausted the oil reserves in the present producing zones and are prevented by growth of the city of Los Angeles from exploiting possible deeper oil sands.

The accompanying table gives a summary of the significant geologic, historical, and economic data concerning all the oil fields in the Los Angeles Basin.

SOME TYPICAL OIL FIELDS

DOMINGUEZ

The Dominguez oil field, 14 miles (23 kilometers) south of the city of Los Angeles, occupies the higher part of Dominguez Hill, one of the prominent topographic features of the Newport-Inglewood uplift. The field was discovered by the Union Oil Co. in September, 1923, and since that time development has proceeded in a systematic manner with the drilling of 97 producing wells, which, prior to May 1, 1931, had yielded 47,000,000 barrels (7,472,000,000 liters) of oil. Acreage has been so controlled that the field has been entirely free from the closely spaced town-lot drilling that is so common to many of the fields in the Los Angeles Basin. Dominguez is an excellent example of an oil field developed in an orderly manner under a uniform well-spacing program. It is the first field in California in which gas was injected for the double purpose of storing the gas and increasing the ultimate oil recovery. Production from the field during 1931 averaged about 10,000 barrels (1,590,000 liters) a day, with wells partly shut in owing to a general oversupply of oil.

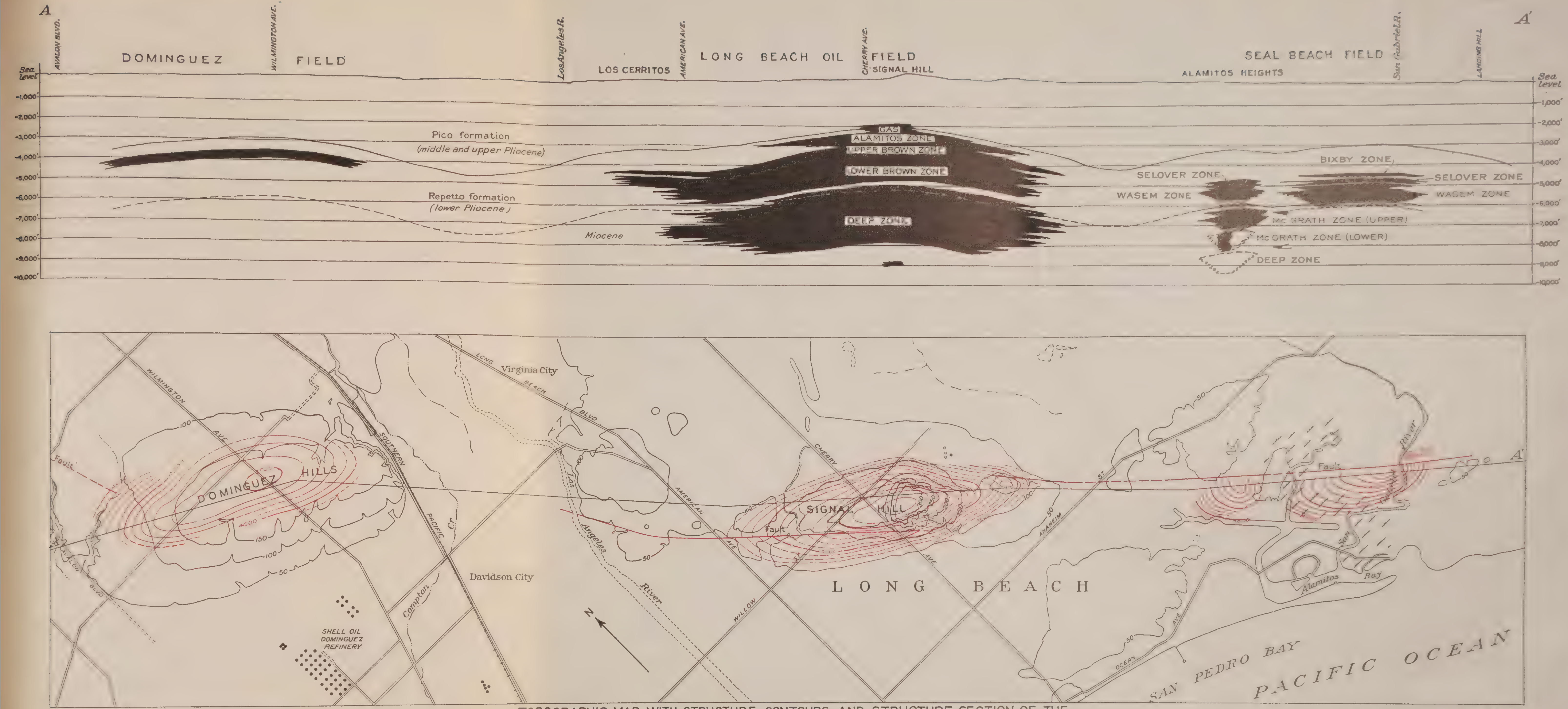
Although the detailed geology of the Dominguez oil field appears to be complex, the general features are comparatively simple. Structurally it is a somewhat asymmetric anticline 2½ miles (4 kilometers) long and three-fourths of a mile (1.2 kilometers) wide, whose only surface expression is a broad hill formed by Quaternary deformation and having the shape of an elongated dome. The axis of the anticline roughly parallels but lies about 1,000 feet (305 meters) north of the crest of Dominguez Hill. Plate 8 illustrates only in a general way the structure of the field and reveals the depth of producing wells and the stratigraphic occurrence of the productive oil zones. Except for a few hundred feet of continental and marine Pleistocene sand, clay, and gravel, all the rocks above the bottom of the producing oil zone (May, 1931) are of Pliocene age; this oil zone, the Callender, is of lower Pliocene age (upper part of Repetto formation).

LONG BEACH

The Long Beach or Signal Hill oil field, about 4 miles (6.4 kilometers) southeast of the Dominguez field, near the north edge of the city of Long Beach, has been one of the two most productive fields of the Los Angeles Basin. It was discovered by the Shell Oil Co., of California, in June, 1921. The peak production of 259,000 barrels (44,964,000 liters) a day from about 289 wells was obtained in October, 1923; prior to May 1, 1931, when the daily production amounted to 88,000 barrels (13,990,000 liters) with 880 wells producing at about half of their capacity, a total of 430,000,000 barrels (68,365,000,000 liters) of oil had been taken from this field. Unfortunately, almost all the land within the field had been subdivided into town lots before the discovery of oil; as a result a forest of closely packed derricks now stands as a monument to hectic drilling campaigns in which operators on adjoining small lots were striving to obtain the maximum amount of oil. Under these conditions development proceeded in a most disorderly manner, with the number of drilled wells entirely out of proportion to the total amount of oil recoverable. (See pl. 7.)

Long Beach is another Los Angeles Basin field where general geologic structure is reflected by striking topographic features resulting from deformation during the Quaternary period. (See pl. 8.) The elongate anticlinal character of the field is indicated by a few exposures of gently dipping soft Pleistocene sandstone and a low smooth-topped ridge whose 3 miles (4.8 kilometers) of length and 1 mile (1.6 kilometers) of width outline in a general way the productive area. Prominent topographic scarps along the southwest side and a part of the northeast side of the ridge have resulted from displacements along steeply dipping faults. These faults, however, have had only a minor effect upon the accumulation of oil, for production has been obtained beyond them, in adjoining low-lying areas. Subsurface evidence for the fault along the southwest side is reported to occur in the deeper producing oil zones, although the amount of displacement can not be accurately determined; the fault indicated by the prominent scarp along the northeast side of the eastern part of the field is reported to have been recognized in subsurface strata.

Production has been obtained from about 5,000 feet (1,524 meters) of rocks which have arbitrarily been divided into four major oil zones. The upper three zones—the Alamitos, Upper Brown, and Lower Brown—are of lower Pliocene age (Repetto formation); the fourth or Deep zone is commonly considered to be largely upper Miocene. The Pliocene-Miocene contact is



Base from U.S.Geological Survey maps of Compton, Clearwater, and Long Beach quadrangles

TOPOGRAPHIC MAP WITH STRUCTURE CONTOURS AND STRUCTURE SECTION OF THE DOMINGUEZ, LONG BEACH, AND SEAL BEACH OIL FIELD

1 ½ 0 1 2 MILES

1 0 1 2 3 4 KILOMETERS

Surface contours in black, interval 50 feet
Structure contours in red, intervals 25, 50, and 100 feet
Datum mean sea level

Compiled by H.W.Hoots with the assistance of data contributed by M.G.Edwards, S.G.W.Wissler, R.M.Barnes, G.H.Bowes, and A.M.Hazzard

Structure contours indicate depth below sea leve and are drawn on the top of the Callender oil zone in the Dominguez field, the top of the Alamitos oil zone in the Long Beach field, and the top of the Selover oil zone in the Seal Beach oil field.

AIRPLANE VIEW LOOKING NORTHWEST ALONG THE AXIS OF THE LONG BEACH OIL FIELD

Note the close relation between the producing area and the low ridge, which reflects the geologic structure very accurately. Rock exposures shown just above the middle of the view reveal upper Pleistocene marine deposits dipping 5° to 35°. Photograph by Fairchild Aerial Surveys (Inc.) Los Angeles.

tentatively considered to occur at a depth of about 5,600 feet (1,707 meters), on the apex of the fold.

SEAL BEACH

The Seal Beach oil field is about 2 miles (3.2 kilometers) southeast of the Long Beach field in an area covered in greater part by tide-land swamps along the lower course of the San Gabriel River. It is another of the chain of oil fields along the Newport-Inglewood uplift. Prior to discovery of the field, interpretation of the structural significance of existing topographic features varied considerably and led to the drilling of 11 dry holes by six different oil companies before the first producing well was completed by the Marland Oil Co., of California (now the Continental Oil Co.), in August, 1926. Oil was soon found to occur not in a single anticline but in two anticlinal folds separated by a nonproductive syncline.

The surface geology and geomorphology of the Seal Beach field are not as simple as those of the Dominguez and Long Beach fields. The existence of a large elongate anticlinal fold is suggested by topographic remnants, northwest and southeast of the San Gabriel flats, of what appears to have been a single ridge about 4 miles (6.4 kilometers) long, 1½ miles (2.4 kilometers) wide, and 75 to 100 feet (23 to 30 meters) higher than the surrounding plain. The growth of this ridge during Pleistocene time was apparently slow and gradual, for the San Gabriel River, an antecedent stream which occupied its present position across this uplift prior to anticlinal folding, succeeded in maintaining its course.

Development of the field has shown that as structural deformation proceeded there were produced along the crest of the uplift a high-angle fault and, instead of a single large anticlinal fold, two closely associated anticlines that have controlled the accumulation of oil. (See pl. 8.) Compared to other productive anticlines of the Los Angeles Basin these two folds are small in areal extent and structural closure. The productive area of the larger anticline contains 330 acres (134 hectares) and 200 feet (61 meters) of closure, and the productive area of the smaller, more dome-shaped anticline contains 110 acres (45 hectares) and 100 feet (30 meters) of closure. The productive area of the Long Beach field contains about 1,200 acres (486 hectares) and 1,000 feet (305 meters) of closure, and that of the Dominguez field contains about 700 acres (283 hectares) and 500 feet (132 meters) of closure.

From the discovery of the field to May 1, 1931, 206 wells had been drilled in, and about 54,000,000 barrels (8,585,00,0000

liters) of oil had been obtained from these two closely associated folds. This is an average of about 262,000 barrels (41,655,000 liters) to the well and about 123,000 barrels (19,555,000 liters) to the acre. Peak production was reached in June, 1927, when 150 wells yielded a daily average of 500 barrels (79,494 liters) to the well, or a total daily production of 75,000 barrels (11,924,000 liters). The initial daily production of individual wells has ranged from a few hundred barrels to 5,000 barrels (744,940 liters), depending on the character and thickness of the producing sands and the structural position of the wells. Most of the wells were at first naturally flowing wells, but many of them now flow by gas lift. During the early stages of development gas-oil ratios were low, ranging from 100 to 3,500 cubic feet (2.8 to 98 cubic meters) of gas to the barrel (159 liters) of oil. Repressuring the field by injecting gas into the oil sands has been practiced since 1927. The oil has an average gravity of about 27° A. P. I. and a gasoline content of about 25 per cent.

Productive oil sands in the Seal Beach field are distributed through about 3,600 feet (1,097 meters) of stratigraphic section and are grouped into five major oil zones—from the top down, the Bixby, Selover, Wasem, upper McGrath, and lower McGrath. Depths to important stratigraphic horizons on the top of the structure are as follows: Top of the Bixby zone 4,300 feet (1,310 meters); top of the Selover zone 4,550 feet (1,387 meters); top of the Wasem zone 4,870 feet (1,484 meters); top of the Miocene 5,775 feet (1,760 meters); top of the McGrath zone 5,920 feet (1,804 meters). The three upper oil zones are of lower Pliocene age (Repetto formation), and the two lower zones are upper Miocene. A still deeper zone is indicated by one well 9,054 feet (2,760 meters) deep, which during May, 1931, produced a small amount of oil, but this zone has not yet proved commercially productive.

SECTION FROM THE REPETTO HILLS TO THE LONG BEACH OIL FIELD

By Ralph D. Reed

REPETTO HILLS

The hills in northern Los Angeles and western Alhambra form part of a broad, low ridge which, under several local names, extends from the east end of the Santa Monica Mountains to the northwest end of the Santa Ana Range. In the area here under discussion the ridge is narrow as well as low and is cut by several north-south valleys, some of which are not now occupied by streams.

The hills are underlain by a thick and complexly deformed series of Miocene, Pliocene, and Pleistocene strata of conglomerate, sandstone, siltstone, and shale. In the upper Miocene many beds of siliceous and diatomaceous shale are included. The total thickness of this sedimentary series, which rests on pre-Tertiary granitic and metamorphic rocks, is approximately 11,000 feet (3,353 meters).

The Miocene rocks may be seen in many street cuts east of Lincoln Park adjacent to Valley Boulevard ("Pomona Boulevard" of the Alhambra topographic map). Upper Miocene (Puente) diatomaceous shale and interbedded sandstone are exposed near City Terrace.

From Alhambra the route turns south along Atlantic Boulevard ("Wilson Avenue") to the Repetto Hills. The Miocene-Pliocene contact is not well exposed along this route but lies near Garvey Avenue, at the north edge of the hills. A block south of Garvey Avenue there is an excellent exposure of lower Pliocene siltstone (Repetto formation) [4] along the west side of Atlantic Boulevard. Although the horizon of the rocks exposed

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[4] The name Repetto formation is here used for the siltstone exposed in the Repetto Hills. This name was proposed in 1930 by a committee of the Pacific section of the Society of Economic Paleontologists and Mineralogists and is now in general use among California geologists. The type locality lies along the west side of Atlantic Boulevard, where the exposed thickness is about 2,000 feet (610 meters). Foraminifera are abundant in this section, and the faunal zones can be correlated with those in the Seal Beach field, where they were first worked out, and in other fields in the Los Angeles Basin. The lower part of the formation is not exposed along Atlantic Boulevard but may be imperfectly seen along Fremont Avenue, half a mile (0.8 kilometer) farther west, where an additional thickness of 500 feet (152 meters) is represented by poorly exposed siltstone that carries only a few fossils. The siltstone rests on diatomaceous shales referred to the Puente formation, but the actual contact is on soil-covered slopes. The top of the Repetto formation is drawn at the top of three beds of coarse feldspathic sandstone ranging in thickness from a few inches to several feet. Siltstone similar to the siltstone of the Repetto formation overlies the sandstone. It carries a mixture of Repetto Foraminifera, possibly reworked, and others characteristic of younger horizons and probably represents the lower part of the Pico formation.

The Repetto formation is a mappable unit in the Repetto, Puente, and San Pedro Hills and in Ventura Basin. On account of its stratigraphic position and distinctive foraminiferal fauna it is referred to the lower Pliocene. Large fossils are very rare in it.

The lower part of the type section of the Pico formation, which lies along the south side of the Santa Clara Valley in Ventura Basin, may include beds of Repetto age, but the facies is different and the section is incomplete. The total thickness of the Santa Paula formation of Eaton in the type section in Adams Canyon, along the north side of Santa Clara Valley, is 9,250 feet (2,819 meters). The lower 1,750 feet (533 meters) carries Foraminifera characteristic of the Repetto formation, but the base is not exposed. It is suggested that the name Santa Paula formation be restricted to the overlying 7,500 feet (2,286 meters) consisting principally of sandstone, probably of early middle Pliocene age.

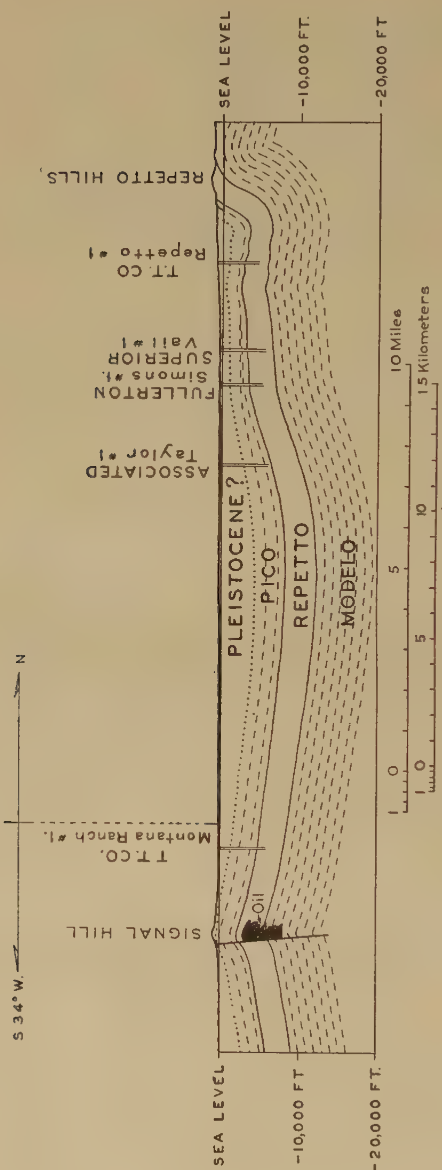


FIGURE 3.—Structure section from Repetto Hills to Signal Hill

is approximately that of the prolific oil sands of Santa Fe Springs, Signal Hill, and other great oil fields of the Los Angeles Basin, no essential body of sandstone is present in the Repetto Hills. This is remarkable, because of the existence of thick conglomerate beds at approximately this horizon in the west end of the Puente Hills, 10 miles (16 kilometers) southeast of Alhambra.

Farther south, in street cuts west of Atlantic Boulevard, practically continuous exposures of lower Pliocene siltstone (Repetto formation) may be seen. These outcrops carry the several foraminiferal assemblages of the zones first discovered in samples from oil wells of the Los Angeles Basin.

Conformably overlying the lower Pliocene siltstone are similar but locally more sandy and even conglomeratic beds of upper Pliocene and possibly Pleistocene age. The whole series dips steeply southward under the Los Angeles Plain. It underlies the entire plain, like the Miocene beds found farther north, but the formations have a considerable range in thickness and lithology in different areas. Toward both east and west, moreover, they come to overlie thick deposits of earlier Miocene, Eocene, and Cretaceous age, which are absent in the Los Angeles area—either not deposited or now eroded. The Los Angeles Basin, in other words, seems to be entirely a feature developed since lower Miocene time.

MONTEBELLO FIELD

From the south edge of the Repetto Hills the Montebello oil field may be seen on a low anticlinal hill that forms the southeast extremity of the Repetto Hills. The wells in this field, like those of Santa Fe Springs and many other fields, yield oil from sandstones found within the Repetto formation. The depth of the wells ranges from 2,000 to 6,000 feet (610 to 1,289 meters).

SIGNAL HILL

On a clear day Signal Hill and the Long Beach field may also be seen, about 15 miles (24 kilometers) away to the south, from the south edge of the Repetto Hills. Signal Hill is a small knoll rising above the long, low ridge that rather accurately reflects the position and structure of the Long Beach anticline. A similar anticlinal ridge, which forms the Dominguez oil field, also composed of arched Pleistocene strata, may be seen farther to the right, northwest of Signal Hill. The route along Atlantic Boulevard from the Repetto Hills to Long Beach passes 2 or 3 miles (3.2 to 4.8 kilometers) east of it, but near enough so that the derricks can be seen.

At Signal Hill itself the chief features of interest, aside from the closely spaced oil wells, are the steeply dipping fossiliferous Pleistocene beds, the antecedent stream crossing the ridge west of Signal Hill, and the terrace on the south side. This terrace appears to mark the location of a small fault which has displaced the arched Pleistocene beds and the smooth surface of the hill. Many similar features, some definitely known to be due to faulting, are found in other anticlinal hills of the Los Angeles Basin. Several of these hills, including those at Huntington Beach, Seal Beach, Dominguez, Athens, and Inglewood, may be seen from Signal Hill if the weather is clear. These anticlinal hills lie along the Newport-Inglewood "fault," a structural feature whose character and even existence is still subject to discussion.

SAN PEDRO HILLS

By W. P. Woodring

INTRODUCTION

The San Pedro Hills constitute a terraced headland jutting into the ocean along the edge of the Los Angeles Basin. Morphologically this headland is one of the Channel Islands, but it is tied to the mainland by the alluvium that covers the basin.

The stratigraphy of the hills is diagrammatically represented in Figure 4. The Jurassic (?) metamorphic rocks are confined to a small area in the central part of the hills. Their most conspicuous constituent is a glaucophane schist that yielded readily recognized débris to the younger sediments. In striking contrast to the section in the Santa Monica Mountains, where more than 10,000 feet (3,048 meters) of Upper Cretaceous, Eocene, and Oligocene or lower Miocene deposits are found, the next younger rocks are of middle Miocene age (Topanga formation). They consist of conglomerate and sandstone carrying Temblor mollusks. The overlying upper Miocene beds (Modelo formation) consists of four members—in ascending order (1) sandstone and siltstone carrying Foraminifera of the *Valvulineria californica* zone, (2) siliceous shale, (3) diatomite, (4) radiolarian mudstone.

The middle Miocene sediments and the lowermost member of the upper Miocene are intruded by basalt. A foraminiferal siltstone referred to the lower Pliocene (Repetto formation) rests on the upper Miocene. The contact may be disconformable, but the evidence is inconclusive. Folding, the results of which are visible throughout the hills, followed the deposition of these beds. Three mappable units of marine early Pleistocene

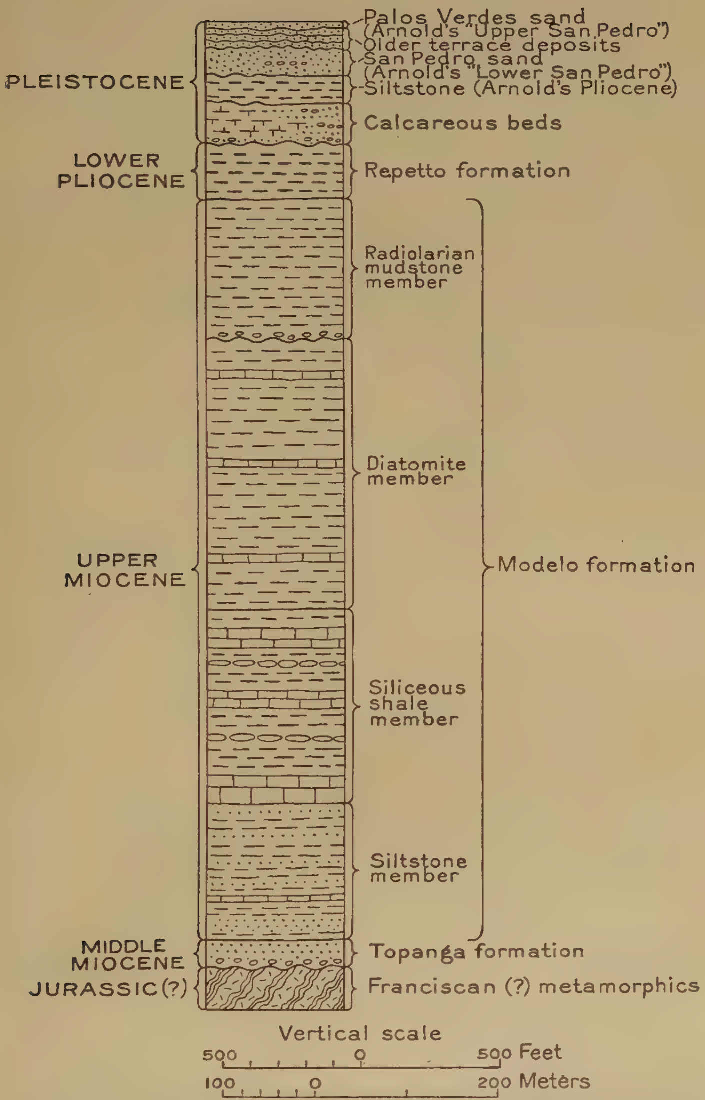


FIGURE 4.—Diagrammatic stratigraphic section in San Pedro Hills

deposits, consisting in ascending order of calcareous beds, siltstone (Arnold's Pliocene), and sand (San Pedro sand),[5] were laid down after this period of folding. They crop out only along the north and east sides of the hills. Then followed another period of folding of mid-Pleistocene age. After this folding the hills were almost or completely submerged and then emerged with a pulsating movement. During this raise the terraces that are a conspicuous feature, especially on the windward side of the hills, were formed. They have a thin veneer of marine deposits overlain by slope-wash alluvium. Fossiliferous marine deposits have been recognized on terraces ranging in altitude from the lowest to one at an altitude of 925 feet (282 meters). The deposits on the lowest terrace constitute Arnold's "upper San Pedro," now called the Palos Verdes sand.[5] The terraces are tilted, especially on the north slope, and along a mobile zone at the north edge of the hills the lowest terrace is folded.

The water front at San Pedro is a classic region in California geology as the result of the work carried on there by Arnold. The faunas of the Pleistocene formations have different temperature facies, and these differences have been interpreted as the result of the climatic changes attending glaciation and deglaciation. An alternative view, which has much to support it, is that the three early Pleistocene formations are not very different in age and that the faunal differences are an expression of differences in depth and other ecologic factors. The lowest terrace deposit (Palos Verdes sand), which, in the glacial-interglacial scheme falls in the last interglacial stage, is relatively much younger than the other beds referred to the Pleistocene.

ITINERARY

San Pedro Hills.—As the San Pedro Hills are approached, the terrace profiles on the east side are clearly visible. Harbor Boulevard skirts the east edge of the outlying part of the hills. The deposits on the lowest terrace (Palos Verdes sand) can be seen along the bluffs, and at places the contact with the underlying early Pleistocene deposits (San Pedro sand) is visible. At many localities along this route marine shells are abundant in the cleanly washed sand and gravel at the base of the deposits

[5] For several years California geologists, following a manuscript usage by Kew, have restricted the name San Pedro formation to Arnold's "lower San Pedro" and have used Kew's new manuscript name Palos Verdes formation for Arnold's "upper San Pedro." The earliest printed record of this usage is in Tieje, A. J., The Pliocene and Pleistocene history of the Baldwin Hills, Los Angeles County, Calif.: Am. Assoc. Petroleum Geologists Bull., vol. 10, pp. 502–503, 1926.

on the lowest terrace. A large part of the city of San Pedro is built on this terrace. The fossiliferous gravel at the base of these beds is seen on the grade up to the terrace.

Second Street, San Pedro.—At Second Street, east of Pacific Avenue, the early Pleistocene calcareous beds dip 22° NE. Fossils (calcareous algae, foraminifers, bryozoans, mollusks, and ostracodes) are abundant in these beds. They are overlain by massive buff siltstone (Arnold's Pliocene). The contact is not very sharp, apparently owing to reworked calcareous material at the base of the siltstone. Several fossiliferous layers may be seen in the siltstone, but time and patience are required to collect the fragile shells. The fauna of the siltstone has a distinctly lower temperature facies than that in the calcareous beds. Above the massive siltstone lies bedded siltstone, the beds becoming progressively thinner upward, and beds of gray sand that become progressively thicker upward appear. The lowest bed of sand is arbitrarily taken as the base of the next younger formation (San Pedro sand). This is a gradational contact, but on Deadman Island—a small remnant of the lowest terrace on the east side of the channel to the harbor, destroyed in 1927–28—the contact was disconformable. The deposits on the lowest terrace (Palos Verdes sand), lying with initial gentle seaward dip, unconformably overlie all these beds. Large shells of the gaper clam (*Schizothaerus nuttallii*) may be seen in their burrows extending down from the contact, oriented in the position in which they lived when the lowest terrace was planed off.

Eastward (upward in the section) the dip flattens, and cross-bedded sand appears in the early Pleistocene (San Pedro) sand. At Second Street and Beacon Avenue this cross-bedded sand is overlain by bedded sand dipping a few degrees northeastward. Two layers carrying well-preserved shells lie at the top of this sand. These fossils have a temperature facies of intermediate aspect. Here also the deposits on the lowest terrace (Palos Verdes sand), consisting mostly of dark brick-red alluvium carrying gravel pockets at its base, unconformably overlie the early Pleistocene (San Pedro) sand.

Gaffey Street.—Gaffey Street follows an abandoned stream channel cut across the arched lowest terrace. The deposits on the lowest terrace (Palos Verdes sand) dip northward into the trough of a syncline that coincides with the valley opening up on the west. Northward from the syncline it rises across an anticline, the crest of which is crossed at the south end of the first sump on the east. This anticlinal crest coincides with a bulge in the profile of the abandoned stream bed, indicating that very recent arching of the anticline forced the abandon-

ment of the stream course and backed up the drainage in Bixby Slough. Early Pleistocene sand and gravel (San Pedro sand) are exposed in cuts along Gaffey Street. In going westward along the Redondo-Wilmington Boulevard the east end of the Torrance oil field, which was discovered in 1922 and reached its maximum production in 1924, is seen on the north.

Lomita quarry.—In the hills south of Lomita the deposits on the lowest terrace (Palos Verdes sand) form a dip slope down to the edge of the hills on the north flank of the same anticline that is crossed by Gaffey Street. The cross-bedded sand and gravel exposed in the sand pit on the west represent the detrital facies of the early Pleistocene calcareous beds. They embrace a few thin tongues of calcareous material greatly diluted by granitic débris that was carried across the Los Angeles Basin. Upper Miocene radiolarian mudstone is exposed along the crest of the anticline 500 feet (152 meters) south of the sand pit. South of the anticline the detrital facies of the calcareous beds fingers into the calcareous facies. At the Lomita quarry the calcareous beds rest unconformably on lower Pliocene foraminiferal siltstone (Repetto formation). The contact is exposed in the ravine at the north edge of the quarry. Several different facies of zoogenous calcareous material can be examined in the quarry. The most conspicuous are a glauconite-*Globigerina* sand, a foraminiferal fine sand, and a harder algal-bryozoan rock. Mollusks are relatively scarce in these beds. The pebbles that have a phosphatic rind and the huge boulders derived from the lower Pliocene and upper Miocene beds are other striking features. According to the records of bore holes, the calcareous beds are thickest in the syncline, the trough of which lies 500 feet (152 meters) south of the quarry. It is inferred that the syncline was a trough at the time the beds were laid down and that the water in which the calcareous beds accumulated was protected from the flood of sand coming from the north by a bar along the site of the anticline, movement along which has taken place repeatedly since the beginning of Pleistocene time.

Ravine west of Walteria.—From the Lomita quarry the route lies northwestward along the edge of the hills. In the fifth ravine west of Walteria the early Pleistocene calcareous beds, consisting of fossiliferous sandy marl and sand, are faulted against upper Miocene radiolarian mudstone and dip 75° N. (See fig. 5.) They are overlain unconformably by the deposits on the lowest terrace (Palos Verdes sand), which here dip 26° N. Two gravel beds lie in these deposits, in the lower one of which a few marine fossils were found.

West end of San Pedro Hills.—Proceeding northwestward the Redondo-Wilmington Boulevard enters an area of wind-blown

sand adjoining the ocean. At the south edge of the town of Redondo the road that leads southward is taken. Off to the south can be seen the cleanly cut terrace profiles. The road continues over the wind-blown sand and enters the Palos Verdes Estates. After crossing a deep ravine cut through the sand into

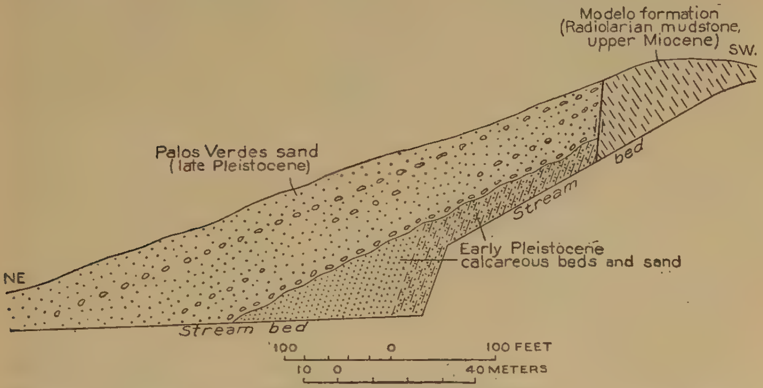


FIGURE 5.—Section exposed in fifth ravine west of Walteria, at north edge of San Pedro Hills

the underlying upper Miocene diatomite the descent is made from the second terrace to the first. On this descent the diatomite and overlying terrace deposits are exposed in cuts. At this locality storm-driven shells were found in a niche in the diatomite that was sealed by boulders and cliff débris and thus converted into a veritable trap. This is the only place where off-

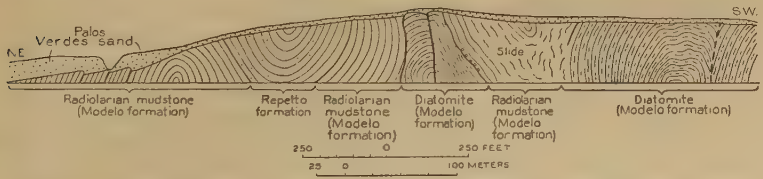


FIGURE 6.—Cliff section at Malaga Cove, on west side of San Pedro Hills. Heavy lines indicate faults (dashed line where concealed)

shore shells were found in terrace deposits on the windward side of the hills. At other localities only cliff and tide-pool fossils were discovered.

Malaga Cove.—The results of the deformation during the first period of folding (Pliocene or early Pleistocene) are well shown in the cliff section at Malaga Cove. (See fig. 6.) The cliffs also afford an opportunity to examine the upper Miocene

diatomite and radiolarian mudstone and the lower Pliocene foraminiferal siltstone. Much of the diatomite is laminated, layers rich in diatoms alternating with layers consisting principally of altered volcanic ash. This lamination may represent a seasonal flowering of diatoms, but it is more probable that the rhythm embraces many years. Some of the layers of ash are minutely brecciated. Only the unusually large diatoms can be seen with the unaided eye or with a hand lens. High on the cliff on the north limb of the first syncline (from the south end) can be seen a ribbon of schist pebbles at the base of the radiolarian mudstone. Large globular Radiolaria are visible in these beds. The lower Pliocene siltstone crops out in the second syncline (from the south end). Foraminifera and glauconite grains are abundant in this siltstone, which represents a small part of the lower Pliocene deposits that embrace the principal oil-bearing beds in the fields of the Los Angeles Basin. The foraminiferal fauna found here was known from well cores before it was discovered at the outcrop. Farther up the beach (northward) massive radiolarian mudstone and laminated diatomite alternate on a large scale in the upper Miocene beds. Here several bedding dip-slip faults are revealed by displacement of the contact with the overlying sand. This sand, which unconformably overlies the Miocene and Pliocene beds, is referred to the lowest terrace (Palos Verdes sand).

GENERAL GEOLOGY OF THE EASTERN PART OF THE SANTA MONICA MOUNTAINS

By H. W. Hoots

The eastern part of the Santa Monica Mountains (pl. 9) forms the northern border of the western third of the Los Angeles Basin. This prominent structural uplift is flanked by upper Miocene rocks which, within the Los Angeles Basin, are found at depths of 5,000 to 8,000 feet (1,524 to 2,438 meters) along the axes of major anticlines. The Pliocene rocks that are so extensive within the basin are faulted down and their outcrops concealed beneath alluvium along most of the southern border of these mountains.

The accompanying table gives a list of the rock formations exposed in the eastern part of the Santa Monica Mountains and information regarding their probable age and general characteristics.

Rock formations exposed in the eastern part of the Santa Monica Mountains

Geologic age	Formation	Approximate thickness (feet)	Character
Recent	Alluvium	0–100	Breccia conglomerate, sandstone, and silt.
Pleistocene	Alluvial-plain deposits now uplifted and deeply dissected.	0–300	Poorly sorted reddish-brown breccia conglomerate and sandstone with earthy matrix and indistinct bedding. This alluvial plain, now far above present level of drainage, has been named Santa Monica Plain.
	Marine upper Pleistocene	5–100	Fossiliferous soft gray sandstone, sandy clay, and conglomerate.
	Unconformity.		
	Upper Pliocene or lower Pleistocene.	100	Fossiliferous conglomerate sandstone and sandy clay.
Unconformity (gently dipping upper Pliocene or lower Pleistocene rests directly upon Pliocene dipping as much as 70°).			
Pliocene	Pliocene, upper and lower	1,000	Soft dark-gray clay and sandstone with lenses and concretions of yellowish-gray limestone. Exposed only in coastal belt northwest of Santa Monica.
	San Diego formation (middle or upper Pliocene).	0–35	Massive soft light-gray conglomeratic sandstone.
Unconformity (some folding and erosion but extent uncertain because of scanty distribution of Pliocene).			
Upper Miocene	Modelo formation	2,300	White punky diatomaceous and foraminiferal shale and fine sandstone, grading laterally into clay shale and sandstone.
		2,250	Soft light-gray to brown well-bedded shale, banded hard platy siliceous shale, thin and thick massive beds of sandstone and conglomeratic sandstone, and volcanic ash. Much of shale is foraminiferal.
Unconformity (represents the most pronounced pre-Pliocene deformation, which included folding, faulting, and basalt intrusion).			
Middle Miocene	Topanga formation	4,500–7,500	Massive fossiliferous sandstone and conglomerate and thin-bedded shale and sandstone intercalated with intrusive and extrusive basalt and pyroclastic rocks of lower and upper Topanga age. Basal 1,000 feet of conglomerate between Stone Canyon and Cahuenga Avenue may be Vaqueros.

Rock formations exposed in the eastern part of the Santa Monica Mountains—Continued

Geologic age	Formation	Approximate thickness (feet)	Character
Lower Miocene (?) and Oligocene (?).	Vaqueros (?) and Sespe (?) formations.	3,500–4,000	Light-gray and red conglomerate and conglomeratic sandstone. Unfossiliferous.
Unconformity (a notable stratigraphic gap produced, at least in part, by folding and erosion of uncertain magnitude).			
Lower Eocene	Martinez formation	250+	Soft brown shale, sandy shale, and sandstone, with hard limestone concretions containing fossils. Prominent discontinuous reefs of white algal limestone.
Upper Cretaceous	Chico formation	8,000+	Massive brown and gray conglomerate and sandstone and dark-gray shale. Fossiliferous. May also contain reefs of white algal limestone.
Unconformity (not exposed, but unquestionably present because of striking difference in metamorphism of Cretaceous rocks and older slates, exposed contacts of which are faults).			
Jurassic (?)	Granitic intrusion	----------	Granite and granodiorite. May be of Paleozoic age.
Triassic (?)	Santa Monica slate	5,000–7,000	Black slate, much of which has undergone contact and regional metamorphism and is locally altered to mica schist. Base not exposed.

Structurally, the eastern part of the Santa Monica Mountains is a broad open anticline, the axis of which lies in the extensive central area of Triassic (?) slate and plunges westward from the major granitic intrusive mass just north of Hollywood. (See fig. 2.) The attitudes of younger rocks, particularly those of Miocene age which cover so much of the north and south flanks of the mountains, conform in a general way to this anticlinal structure. It is apparent from the presence of several pronounced unconformities, however, that this major fold has experienced several stages of growth and deformation. The anticlinal structure is still clear in the central part of the district, but in the eastern and western parts the original fold has been so intricately deformed by block faulting and igneous intrusion that much of the fold is either difficult to recognize as such or is down faulted and concealed beneath alluvium.

About a fourth of the eastern part of the Santa Monica Mountains consists of dark-gray slate which, together with the associated granodiorite, occupies the central or axial part of this low mountain range. Evidence of contact metamorphism of the slate by the Jurassic (?) granitic intrusion is particularly striking; the intrusive mass is bordered by an "aureole" 1,500 to 2,000 feet (457 to 610 meters) wide of mica schist and dark-gray phyllite, which in turn is bordered by an extensive belt of spotted slate that contains dark crystals of cordierite and grades outward into ordinary slate through a broad zone in which the individual cordierite spots become progressively smaller and finally disappear.

Two structural features of this district are particularly striking. One is the unconformity between the middle Miocene and upper Miocene beds. It represents the only period of folding (see accompanying table) of comparable importance to the deformation that occurred near the end of the Pliocene. The other is the remarkably close association between faults and intrusions of basalt in the rocks of the Topanga and Santa Ynez Canyon district that are earlier than upper Miocene—an association which forces the conclusion that faulting and intrusions of basalt had a close genetic relation during the period of Miocene diastrophism.

EXCURSION IN LOS ANGELES BASIN AND SANTA MONICA MOUNTAINS

By H. W. Hoots

The geologic map of the Los Angeles Basin (pl. 6) shows the route of this excursion. The Los Angeles Basin is crossed in a southerly direction, passing through the Dominguez oil field, where there is a modern paleontologic laboratory of one of the large oil companies, with a collection of representative cores of

subsurface formations of the basin. From Dominguez the route passes within view of the Long Beach oil field and through the Watson tank farms, where probably more oil is stored than at any other one locality in the world. The route passes around the north end of the Los Angeles Harbor to the exposures of marine Pleistocene rocks in the town of San Pedro, and thence westward into the San Pedro Hills, where exposures of marine rocks are abundant and where comparatively high altitudes permit views of the Los Angeles Harbor and most of the Los Angeles Basin. The route will follow the coast line that borders the south and west sides of the San Pedro Hills and extends northward to Hermosa Beach, and thence, leaving the coast, will lead to the Inglewood oil field.

In the Santa Monica Mountains there are good exposures of Triassic (?) and Miocene rocks, and excellent views of the Los Angeles Basin and the San Fernando Valley can be obtained.

LOS ANGELES BASIN

Los Angeles.—Southward-dipping marine shale and sandstone of Miocene and Pliocene age are exposed in the city of Los Angeles. Near the center of the business district these rocks pass beneath a mantle of Pleistocene alluvial deposits that conceal all marine strata throughout most of the Los Angeles Basin and form a featureless alluvial plain that slopes gently southward.

Dominguez oil field.—Dominguez Hill, upon which is located the Dominguez oil field, is approached from the northwest. This anticlinal hill is covered by late Pleistocene continental deposits; its symmetrically arched surface is an illustration of the result of late Pleistocene folding. (See p. 27.)

Long Beach oil field.—Views of the Long Beach or Signal Hill oil field may be had from the south flank of Dominguez Hill and from other points farther south. The most striking features of this field are its "forest" of derricks and the tremendous quantity of oil that they have produced. Because of the presence of comparatively recent fault scarps, the topography of this field lacks the uniformity and symmetry characteristic of the Dominguez Hill topography. (See p. 28.)

Watson oil tank farms.—The Watson tank farms, 3 miles (4.8 kilometers) south of Dominguez, provide an interesting picture of oil refineries and methods commonly employed in storing oil. At this locality five California oil companies have a total storage capacity for 38,000,000 barrels (6,041,000,000 liters) of oil. Most of this oil is contained in reservoirs excavated below the surface of the ground and lined with concrete. Capacities

AIRPLANE VIEW OF SANTA MONICA MOUNTAINS

(From U. S. Geol. Survey Prof. Paper 165, pl. 31, 1931.) Photograph by Spence Airplane Photos, Los Angeles.

of individual reservoirs range from 750,000 to 3,000,000 barrels (119,241,000 to 476,964,750 liters).

Los Angeles Harbor.—The route passes along the north end of the Los Angeles Harbor, of which an excellent view is obtained from a higher point in the San Pedro Hills. This harbor is almost entirely artificial, having been developed by dredging a preexisting slough and tide-land swamps. The total outbound commerce handled during 1929 amounted to 21,113,508 long tons and was greater than that of any other American port. Petroleum and petroleum products constitute about two-thirds of the total shipments.

San Pedro Pleistocene deposits.—Three marine formations of Pleistocene age carrying abundant fossils are exposed in the vicinity of San Pedro. Along the water front they have a gentle dip, but farther back from the coast the dip is as high as 22°. These Pleistocene beds are beveled by the late Pleistocene terrace on which a large part of San Pedro is built. Many fossils also are found at the base of the terrace deposits.

San Pedro Hills.—The San Pedro Hills constitute an upland area on the seaward side of the Los Angeles Basin. Morphologically this terraced upland is one of the Channel Islands. The hills are composed principally of Miocene rocks that overlie metamorphic rocks of doubtful Franciscan (Jurassic?) age. The lower part of the Miocene series consists of conglomerate, breccia, sandstone, and siltstone, intruded by basalt. These deposits are overlain by siliceous shale and limestone, followed by diatomite, tuff, and radiolarian mudstone. The oil-bearing lower Pliocene beds of the basin are represented by a few hundred feet of foraminiferal siltstone. A fringe of deformed marine Pleistocene deposits extends along the north and east sides of the hills. Intricately folded Miocene rocks are seen along the route followed on the south and west sides of the hills. The terraces on the west side of the hills are a striking feature.

Malaga Cove.—The sea cliffs at Malaga Cove, at the northwest edge of the hills, afford exposures of the strongly deformed Miocene and lower Pliocene rocks overlain unconformably by Pleistocene sand. Only the uppermost part of the Miocene series, consisting of diatomite and radiolarian mudstone, is exposed here. The lower Pliocene deposits embrace foraminiferal siltstone.

Inglewood oil field.—The Inglewood oil field occupies the central part of the Baldwin Hills, the most prominent topographic feature along the Newport-Inglewood uplift. Elevation of this area, like that of Dominguez, Long Beach, and others to the southeast, resulted largely from anticlinal folding during late

Pleistocene time. In the Inglewood area, however, folding was accompanied or followed by the development of a southwestward-dipping normal fault that cuts diagonally across the general line of folding and separates a major anticline on the west from a smaller dome-shaped anticline on the east. Both folds produce oil, although most of the oil from this field has been obtained from the larger anticline to the west. Producing wells are from 2,000 to 3,200 feet (610 to 975 meters) deep.

The approximate surface trace of the Inglewood fault is marked by a prominent southwestward-facing scarp. The relative fault movement has been down on the west, with the oil zone displaced a maximum of about 500 feet (152 meters). Some geologists believe that this fault is still active and that movement along it caused the Inglewood earthquake of June 21, 1920. Most of the surface of this field is covered by a small thickness of gently tilted late Pleistocene strata, the upper part of which consists of reddish-brown alluvial-plain deposits and the lower part of marine conglomerate and sandstone. These rocks rest unconformably on the more steeply folded upper Pliocene strata, in which occurs the upper part of the present producing oil zone.

SANTA MONICA MOUNTAINS

South flank along Beverly Boulevard.—A short description of the geology of the Santa Monica Mountains is given on pages 40–43. This part of the route follows in general the contact of late Pleistocene alluvial-plain deposits with underlying southward-dipping upper Miocene sandstone (Modelo formation). The Pleistocene alluvial plain, although still readily recognizable, is deeply incised by southward-draining streams whose gradients have been steepened by late Pleistocene elevation of the mountains and tilting of the plain. Minor faults are exposed in Miocene rocks along the southern flank of the mountains, and there is good reason for believing that a major fault zone, concealed beneath the Pleistocene alluvial deposits, parallels the southern base of the mountains.

Santa Monica slate (*Triassic?*).—The party will leave Beverly Boulevard near the northwestern edge of Beverly Hills and travel northward up Brown Canyon or Beverly Glen. The only rocks exposed in the lower 1½ miles (2.4 kilometers) of this canyon are dark-gray Triassic (?) slate (Santa Monica slate) and associated basic intrusive rocks. This slate has resulted from the metamorphism of what probably were once marine sediments, although no fossils have yet been found in it. This formation has an extensive distribution in the central part of the mountains. Two miles (3.2 kilometers) east of Brown Canyon it has

been intruded by granodiorite and altered to schist, phyllite, and spotted slate. Most of the rock exposed in Brown Canyon belongs to the unspotted member of the slate. In general this entire formation is folded into a broad westward-trending anticline, the axis of which lies in the central part of the mountains and plunges westward away from the major intrusion of granodiorite.

Topanga formation (*middle Miocene*).—Northward up Brown Canyon the first sedimentary rocks encountered are massive light-gray middle Miocene conglomerate and sandstone (Topanga formation). These strata, which here dip 70°–90° N., rest directly on the Triassic (?) slate, but the contact is not exposed. A marine molluscan fauna typical of the middle Miocene of California has been collected from these rocks at several localities. The formation has a total maximum thickness of about 7,500 feet (2,286 meters) and includes considerable shale in its upper part. Small intrusive bodies of basalt, abundant in the middle part of the formation, are here well exposed.

Middle Miocene unconformity.—The steeply dipping middle Miocene formation is unconformably overlain by a much more gently folded series of upper Miocene shale and sandstone (Modelo formation). This unconformity marks one of the most intensive periods of diastrophism experienced by this area during the Cenozoic era. The unconformable contact is not exposed in Brown Canyon, but on ridges farther west the upper Miocene, dipping 5°–20° N., overlaps all of the steeply dipping middle Miocene and rests directly on the Triassic (?) slate.

Modelo formation (*upper Miocene*).—Exposures of the lower part of the upper Miocene formation are seen along the upper part of Brown Canyon and eastward along the Mulholland Highway. This part of the upper Miocene is composed of about 2,300 feet (701 meters) of alternating beds of sandstone and siliceous shale and is readily identifiable by the hard platy and cherty character of much of the shale. All these strata are of marine origin and have yielded a variety of fossils. Fish, horse bones, foraminifers, and the leaves of land plants have been found in the platy shale. The upper part of the Modelo occupies the northern edge of the mountains and, in contrast to the lower member, is composed almost entirely of soft white punky diatomaceous shale.

Eastward along Mulholland Highway.—From the head of Brown Canyon the route for this excursion follows the Mulholland Highway eastward along the crest of the mountains. Excellent exposures of structural and stratigraphic features within both the upper Miocene and the middle Miocene beds

are available along the highway. Large sill-like intrusions of amygdaloidal basalt and extrusive bodies of agglomerate are well exposed along the eastern part of the Mulholland Highway, west of Cahuenga Pass, where this route leaves the mountains and enters Hollywood.

LOS ANGELES TO SANTA BARBARA

By William S. W. Kew

INTRODUCTION

The region between Los Angeles and Santa Barbara is underlain almost entirely by strongly folded sedimentary rocks, mainly of Tertiary age. This area is part of an extensive Tertiary basin that extended from the Santa Ynez Mountains on the north to the Santa Monica Mountains on the south and inland at least as far as the San Gabriel Mountains and probably as far as Pasadena. The structural features in the Coast Ranges have a general northwesterly trend, but in this basin they trend approximately east and west. The northwestward-trending features terminate abruptly against those of east-west trend.

In all parts of this region the topographic surfaces are closely related to the structure. The lowlands are structurally low areas where deposition is now in progress; the hills and mountains are structurally high and are undergoing erosion. Fault blocks, such as Sulphur Mountain, San Cayetano Mountain, and Santa Susana Mountain, stand out prominently, and synclinal valleys, such as the San Fernando, Simi, and Santa Clara Valleys, are clearly evident.

Compression has been the dominant factor in the structure of this region, as indicated by the thrust faults and closely compressed folds. Vertical adjustments have also been common, but faulting as the result of tension has been rare.

The principal formations and their characteristics are described below.

QUATERNARY

Terrace deposits.—Recent alluvium and upper Pleistocene terrace deposits cover a considerable area in the flood plains of the valleys and in the coastal basins. A number of terraces mantled by detritus, both marine and nonmarine, are found at various levels along the streams and coast. Both the alluvium and the terrace deposits are composed largely of coarse sand and gravel, usually ill sorted and poorly stratified. At places they are well cemented.

Saugus formation.—The Saugus formation, the type locality of which is in the vicinity of Saugus, 30 miles (48 kilometers) east of Santa Paula, consists of conglomerate, soft sand, and a few beds of sandy clay. It was deposited in a shallow basin and embraces both marine and nonmarine deposits. At the type section it is mainly nonmarine, but in Ventura County the lower part contains several marine faunal zones of Pleistocene age.

PLIOCENE

Pico formation.—The Pico formation is essentially a gray mudstone or siltstone that embraces local lenses of massive conglomerate and sandstone. If a threefold division of the Pliocene is accepted, the Pico formation embraces deposits of upper and middle Pliocene age.

Repetto formation.—The Repetto formation consists of siltstone, sandstone, and conglomerate, which are considerably more indurated than those in the Pico. The main oil-bearing zones of the Ventura Avenue and Rincon oil fields occur in this formation. It is conformable with the Pico formation but contains a foraminiferal fauna characterized by *Plectofrondicularia californica* and associated species, which has been referred to the lower Pliocene. It apparently grades downward into the brown sandy shale that forms the uppermost member of the Modelo formation.

The Saugus, Pico, and Repetto formations are exceptionally well exposed along Santa Paula Creek, where over 23,000 feet (7,010 meters) of Pliocene and Pleistocene strata have been measured.

MIOCENE

Modelo formation.—The type section of the Modelo formation is on the north side of the Santa Clara River in the vicinity of Modelo Canyon, lying between Sespe and Piru Creeks, Ventura County. The section is now known to be, in part, equivalent to the originally defined Monterey formation of the type section in Monterey County. It comprises over 12,000 feet (3,658 meters) of deposits.

The Modelo formation is essentially a clay shale characterized by zones of hard siliceous shale having a light color. In places the upper beds are in part diatomaceous, and locally they attain a high degree of purity. Interbedded with the shales are two lenticular massive sandstones, which at the type locality form about half the thickness of the formation. These rocks extend eastward and form the greater part of the Santa Susana Mountains.

West of Sespe Creek, or in what may be termed the coastal area of Ventura and Santa Barbara Counties, the Miocene series is clearly divisible into three definite lithologic units—the Vaqueros formation, the Rincon formation,[6] and the Modelo formation. Many geologists refer the Modelo shale to the Monterey. The Rincon formation is a well-defined stratigraphic unit that can be traced along the coast for nearly 100 miles (161 kilometers). It consists essentially of a dark-gray clay shale or mudstone, which commonly contains concretions of impure yellow limestone and carries Foraminifera of late lower or early middle Miocene age. Its thickness ranges from 300 to 2,000 feet (91 to 610 meters). The Modelo is mainly shale that can in most places be roughly divided into two parts—a lower siliceous shale (pl. 10, *A*) and an upper clay and diatomaceous shale (pl. 10, *B*) (brown shale member of Ventura County). Both the Rincon and Modelo shales contain very few mollusks. but foraminifers are abundant and occur in definite zones. Diatoms also are found in the upper part of the Modelo.

Vaqueros formation.—The Vaqueros formation, originally described from a locality in Monterey County, has been recognized by means of fossils over a large area in California. It is usually a dark-gray or brown medium to coarse grained sandstone. At the section on Sespe Creek the sandstone grades down into the Sespe red beds and up into the Rincon shale. The limits of the Vaqueros formation are based in places upon fossil evidence alone, though the lower limit is usually placed at the top of the red nonmarine strata of the Sespe and the upper limit at the base of the Rincon shale. The Vaqueros formation is oil-bearing in the Elwood and Capitan fields of Santa Barbara County, where it is about 300 feet (91 meters) thick and is unconformable with the underlying Sespe.

OLIGOCENE AND EOCENE

Sespe formation.—The type section of the Sespe formation lies in the drainage area of Sespe Creek, north of Fillmore, Ventura County. Here it consists mainly of massive but rather well bedded sandstone, separated by siltstone and shale. Conglomerate is common as more or less lenticular beds. The whole formation has a color that ranges from a rusty gray to deep red or maroon. This coloring is one of the characteristic features of the formation. This type of the Sespe formation, which is en-

[6] The name Rincon formation has recently been introduced for the clay shale in the Ventura and Santa Barbara regions lying between the Vaqueros sandstone and the siliceous shale. (See Kerr, P. F., Bentonite from Ventura, California: Econ. Geology, vol. 26, p. 156, 1931.)

tirely terrestrial, extends from Sespe Creek up the coast to Gaviota Pass, in Santa Barbara County, beyond which the beds grade westward into marine gray sandstones and shales.

South to Santa Clara Valley and the San Cayetano thrust fault the lithology is somewhat different, though the formation is of nonmarine origin and retains a certain proportion of red beds. The strata at Oak Ridge and South Mountain are, for the most part, less consolidated and much more diverse in lithologic character. Friable coarse yellowish-brown sandstone and conglomerate interbedded with varicolored sandy shale and shale predominate.

EOCENE

The California Eocene has been subdivided into four major divisions—named in descending order the Tejon, Domengine, Meganos, and Martinez. These units are based principally on fossils, but at places they are separated by unconformities. They are made up of marine sandstone, conglomerate, and shale. Usually one or more of the divisions is absent at any one locality.

Along the route of this excursion two rather different types of Eocene sediments are exposed in the Simi Valley and in the Santa Ynez Mountains. In these areas local names have been given to the divisions. The section in the two areas has been classified as follows:

Simi Valley (after Clark)	Santa Ynez Mountains
Tejon?	Tejon { Coldwater sandstone. Cosy Dell shale. Matilija sandstone.
Domengine.	Undifferentiated middle and lower Eocene.
Santa Susana.	
Martinez.	
Cretaceous.	Cretaceous.

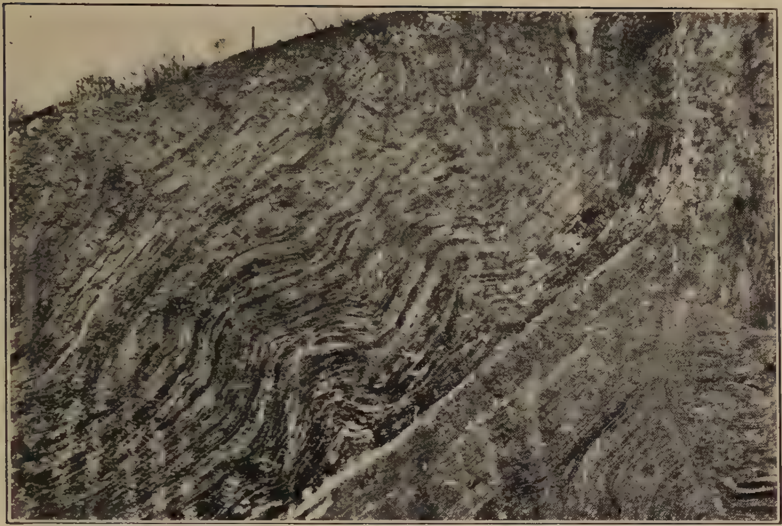
In the Simi Valley the lower Eocene is represented by the Martinez formation, which here contains an abundant and well-preserved fauna. Nelson has divided it into three lithologic members—(1) the Simi conglomerate at the base, which reaches

a maximum thickness of 1,500 feet (547 meters); (2) the Las Virgenes sandstone, which is coarse grained, feldspathic, poorly indurated, and 300 feet (91 meters) thick; (3) the Martinez marine member, with a thickness of 2,400 feet (732 meters), which consists of medium to fine grained sandstones with 200 feet (61 meters) of shale at the top. The Santa Susana formation, overlying the Martinez disconformably and having a distinctive fauna similar to that in the Meganos formation of middle California, is 1,800 feet (549 meters) thick. It is made up of a basal conglomerate, light-colored shale, and sandy shale. The Domengine formation, disconformably overlying the Santa Susana, comprises 1,200 feet (366 meters) of conglomerate, shale, and shaly sandstone. The Tejon (?) formation, consisting of about 1,200 feet (366 meters) of coarse conglomerate, sandstone, and shale, conformably overlies the Domengine. Owing to the lack of fossil evidence, this series of strata is tentatively correlated with the Tejon formation in other parts of California simply on the basis of its position in the stratigraphic section. On the north side of Simi Valley it apparently grades up into the Sespe formation (Oligocene and Eocene).

In contrast with the Eocene of Simi Valley, the section in the Santa Ynez Mountains is composed almost entirely of hard, prominently weathering sandstones and shales having a total maximum thickness of 17,400 feet (5,303 meters). The lower part consists of well-indurated conglomerate, sandstone, and shale, which from fossil evidence are believed to embrace all the Eocene except the Tejon formation. Because of the similarity in lithology and in ruggedness of the terrane no stratigraphic separation has been possible. The upper part, considered of Tejon age, has been divided into three members—a coarse to medium grained buff sandstone, a hard sandy dark olive-gray sandy shale, and an upper sandstone and shale. The upper member, generally known as the Coldwater sandstone, is distinctive owing to the presence of thick beds of nearly white sandstone and red and green shales. It is in part nonmarine and resembles the Sespe formation, which overlies it. The presence of diagnostic fossils definitely places it in the Eocene.

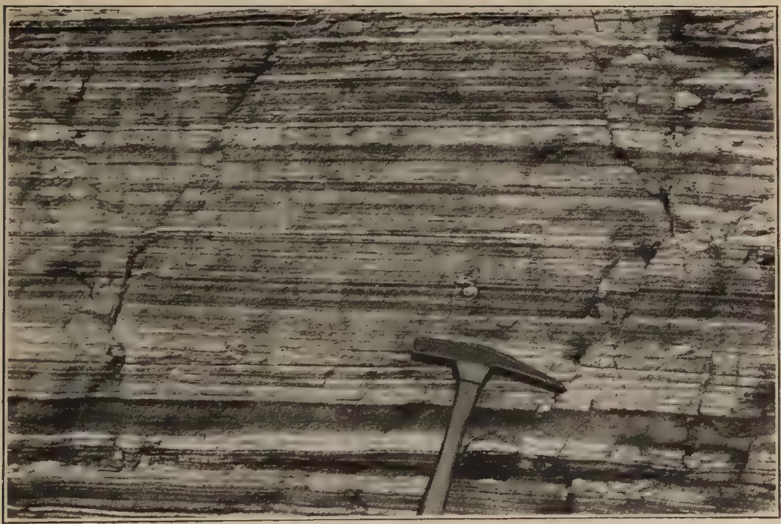
CRETACEOUS

The Simi Hills are composed largely of rocks referred to the Chico formation (Upper Cretaceous). This series of strata consists almost entirely of dark-brown, massively bedded sandstone interbedded with relatively thin streaks of olive-brown shale. No fossils have ever been found in this sandstone. These rocks are well exposed along the route through Santa Susana Pass.



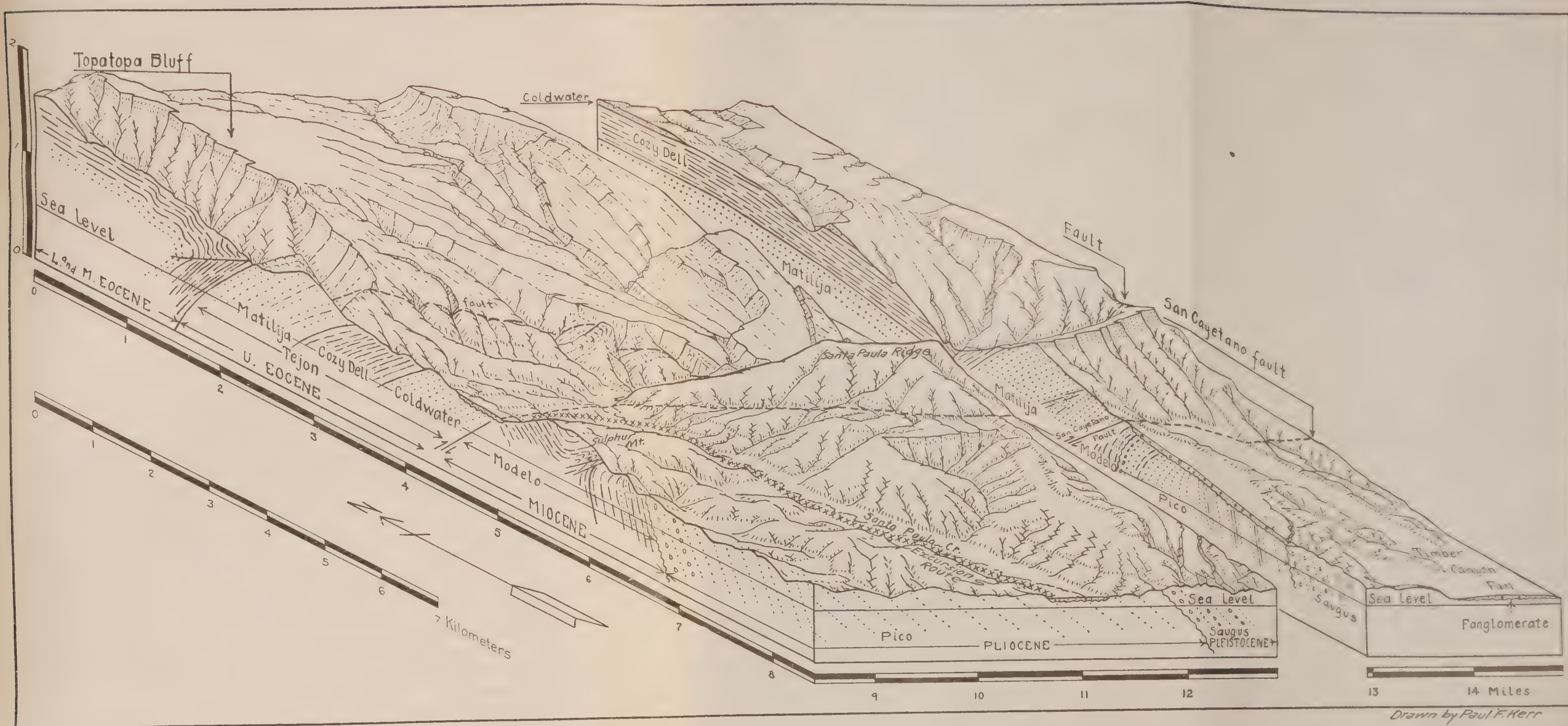
A. GRAY CHERTY SHALE IN LOWER MEMBER OF MODELO FORMATION OF SANTA MONICA MOUNTAINS

Shows folding of incompetent beds above a plane of slippage. (From U. S. Geol. Survey Prof. Paper 165, pl. 24, *A*, 1931.)



B. FINELY LAMINATED WHITE AND LIGHT-GRAY PUNKY DIATOMACEOUS SHALE IN UPPER MEMBER OF MODELO FORMATION OF SANTA MONICA MOUNTAINS

Just south of Ventura Boulevard and east of Girard. (From U. S. Geol. Survey Prof. Paper 165, pl. 25, *C*, 1931.)



TOPOGRAPHY AND STRUCTURE OF HIGHER MOUNTAINS NORTH OF SANTA PAULA

At various places in the Santa Ynez Mountains strata of both Lower Cretaceous (Knoxville) and Upper Cretaceous (Chico) age are present, but none of these beds are exposed along the route to Santa Barbara. The Chico is composed of hard gray and brown sandstone and dark-gray shale, and the Knoxville is largely dark-gray shale with greenish-brown sandstone.

ITINERARY

Los Angeles.—Leaving the Southern Pacific station the route passes northward along the narrow channel of the Los Angeles River, which drains the San Fernando Valley. (See pl. 11.) The hills pierced by the river connect the Santa Monica Mountains with the Repetto and Puente Hills. At Elysian Park, along the west side of the river, the rocks seen in the railroad cut consist of middle Miocene sandstone and upper Miocene shales. They form the south limb of an extensive anticline, the axis of which lies in the bed of the river to the north of the hills. Progressively younger beds, extending up into the younger Pliocene, are exposed on the south flank of the anticline farther south in Los Angeles. On Fifth Street opposite the public library the upper Pliocene fossiliferous beds were excellently exposed. The strata in the hills east of the river consist mainly of highly folded and faulted middle and upper Miocene beds.

San Fernando Valley.—San Fernando Valley, 21 miles (34 kilometers) long and 9 miles (14 kilometers) wide, is a large synclinal depression filled with Tertiary and Quaternary deposits. They rest presumably on Cretaceous deposits and pre-Cretaceous crystalline rocks. The depth of the deposits in San Fernando Valley varies from place to place, but wells drilled to a depth of more than 6,000 feet (1,829 meters) fail to penetrate the Miocene rocks except along the margin. One well at the east end found the Pleistocene gravel to be 1,460 feet (445 meters) thick. At its east end the valley is terminated by a fault along which rises the granitic mass of the Verdugo Mountains, which is essentially part of the San Gabriel Mountains.

The cities of Glendale and Burbank are built on alluvial fans at the foot of the Verdugo Mountains. The Glendale fan is made up of granitic detritus brought down through Verdugo Canyon by an antecedent stream that cuts these hills. The Burbank fan has been built up from débris washed down from the adjacent hills.

Verdugo Mountains.—The Verdugo Mountains consist of a fault block of granitic rocks more or less triangular in outline and faulted at least on its two longer sides (north and south). The fault on the south side is much more prominent and lies at

the base of the bold front, which extends in an almost straight line from Pasadena to Pacoima, on the Southern Pacific Railroad. This fault-line scarp is exceptionally well displayed from the highway north of Burbank. The northwest end of the Verdugo Mountains is covered with Miocene sandstones and conglomerates, and a short distance east of Pacoima an isolated hill, geologically a part of the Verdugo Mountains, stands above the alluvium. The south side of this hill consists of granite overlain by northward-dipping Miocene sediments and basalt flows.

San Gabriel Mountains.—To the east, between Pacoima and San Fernando, can be seen the San Gabriel Mountains. The western part of this range rises to an altitude of over 5,000 feet (1,524 meters) above sea level. East of San Fernando, at the foot of the mountains, a series of sedimentary strata of Miocene and Pliocene age can be seen dipping northward toward the crystalline rocks. These strata form one of the fault blocks of the south side of the San Gabriel Mountains. The main mass and higher parts of the mountains are formed by a huge block of granitic and metamorphic rocks which has been pushed upward. It is bounded on all sides by faults that are for the most part of the reverse type. The south side is broken into a number of smaller, northward-tilted blocks, several of which are visible from San Fernando. The topography is controlled mainly by the shapes of these blocks. The highest block is cut off on the north by the San Gabriel fault, the next group by the Sierra Madre fault, and the lowest, which is represented at the surface by Tertiary rocks, by the Tujunga Valley fault.

San Fernando Pass.—Northwest of San Fernando is the San Fernando Pass, through which runs the most direct route to San Joaquin Valley. On the north side of the pass is the Santa Clara River. The San Fernando Pass marks the junction of the crystalline mass of the San Gabriel Mountains with the sedimentary rocks of the Santa Susana Mountains. Some major structural features of the San Gabriel Mountains continue westward, and the Santa Susana Mountains are likewise formed by an uplifted block with a large thrust fault along its south side.

Santa Susana Mountains.—The San Fernando Mission, one of the old California missions, is passed in going westward from San Fernando. To the north lies a low range of hills composed mainly of Pleistocene sand and gravel (Saugus formation). These fairly soft beds all dip northward toward the higher Santa Susana Mountains. A fault, presumably the one that

passes westward down Tujunga Valley, follows the south base of these hills.

From Devonshire Street, in the vicinity of the junction with Reseda Avenue, a good view can be obtained of the south side of the Santa Susana Mountains. The main structure is that of overthrusting from north to south. Two or more lines of faulting are recognized. The fault having the greatest throw lies at the foot of the steep upper slope. A second fault lies at the foot of the low hills, and a probable third fault trends in a northwesterly direction through the intersection of Devonshire Street and Reseda Avenue and forms the line of low hills extending into the valley. Along the upper or Santa Susana fault the Miocene beds (Modelo formation) are thrust over deposits of Pliocene and Pleistocene age. This Pliocene and Pleistocene block has in turn been faulted along a line at the base of the mountains. This movement has occurred in rather recent geologic time, as a capping of terrace sand and gravel has been tilted northward toward the higher or Santa Susana fault. The south edge of this terrace, hanging about 500 feet (152 meters) above the level of the valley floor, is a striking feature in its anomalous position. At one time it was probably a part of the San Fernando Valley, but faulting along the south edge of the valley raised it to its present height. The trace of the Santa Susana fault is well marked north of Chatsworth, where Brown Canyon has cut a steep cirquelike face. Here the underlying light-gray Pliocene and Pleistocene sands are clearly distinguishable from the overlying Miocene yellowish-brown siliceous shale and sandstone (Modelo formation). At the fault line there is a thin layer of basalt.

Recent diastrophism in San Fernando Valley.—Devonshire Street crosses a low line of hills at the north end of Reseda Avenue. These hills consist of late Pleistocene sand and gravel that have been folded at the surface into a gentle anticline. Slightly over a mile (1.6 kilometers) west of this intersection the hills to the north show evidence of faulting, as the Pleistocene strata have been tilted to nearly vertical attitudes. These hills resulted from movement on a fault belonging to the Santa Susana fault system, which is in part expressed at the surface by folding.

Simi Hills.—Near the west end of San Fernando Valley the Cretaceous strata forming the Simi Hills rise abruptly from the alluvium in bold cliffs. The beds dip westward at relatively low angles, and the sandstone seems to be piled in huge blocks. Farther south Upper Cretaceous fossils have been found in the lower part of this formation. The road turns northward at

the town of Chatsworth and, after winding up the side of one of the small canyons, ascends to Santa Susana Pass. From the summit Simi Valley can be seen lying between the Simi Hills on the south and Oak Ridge, the western extension of the Santa Susana Mountains, on the north. The Upper Cretaceous sandstone is exposed in cuts along the road. It is arkosic and yellowish brown and carries a few thin zones of greenish-gray laminated shale. The Simi Hills form an uplifted mass, presumably faulted on the south and east sides. The faults are not visible, but the rather straight, abrupt front and its abnormal position relative to the rocks at the base strongly indicate faulting.

Simi Valley.—Simi Valley is a synclinal depression, as is apparent from the Simi side of Santa Susana Pass (altitude 1,625 feet, or 495 meters). Here the Cretaceous strata can be clearly seen gently folded into a syncline that plunges steeply westward beneath Simi Valley. One of the thickest and most fossiliferous Eocene sections in California is to be found in the hills bordering Simi Valley. Nonmarine upper Eocene and Oligocene beds (Sespe formation) overlie the marine Eocene. They consist of over 5,000 feet (1,524 meters) of sandstone, conglomerate, and clay which are exposed on the north side of the valley and in the road cuts between Simi and Moorpark. These deposits are characterized by reddish and greenish clays interbedded with the brown sandstones. A vertebrate fauna of upper Eocene age has been found in the middle part of these beds.

At the base of the grade on the west side of Santa Susana Pass the road turns due north for 0.6 mile (0.96 kilometer). On this stretch of road a view is obtained of the lower Eocene (Martinez formation) resting disconformably on the Upper Cretaceous (Chico formation). The basal part of the Eocene is composed of coarse conglomerate interbedded with sandstone, all reddish brown. This conglomerate varies from place to place and ranges in thickness from 1,500 feet (457 meters) to the vanishing point. It is overlain by sandstones and shales having a maximum thickness of 2,700 feet (823 meters) at the east end of the valley. Turning west, the route extends down the lowest part of the valley and passes a point just east of Santa Susana, where rocks of middle Eocene age (Domengine formation) are exposed.

Simi oil field.—Directly north of Santa Susana lies the Simi or Tapo Canyon oil field. It is the only field in southern California yielding oil in commercial quantities from the Eocene. The wells start in the lower part of the Sespe forma-

tion and obtain their oil from the upper part of the underlying middle Eocene. The wells are small producers, but the oil is of good quality and, unlike the California Miocene and Pliocene oils, contains a large percentage of paraffin. The field is situated on an anticline extending from Tapo Canyon along the north side of the valley, plunging westward. It is intimately associated with a major fault that follows the foot of the hills and crosses the west end of the valley about a mile (1.6 kilometers) west of Simi. It continues westward for many miles and disappears under the alluvium of Ventura Basin. The accumulation of the oil is due to closure of the anticline against this fault, which is of the reverse type.

Simi Miocene section.—Northward from the railroad crossing, 5 miles (8 kilometers) west of Simi, a good view is available of the section of Miocene formations resting on the Oligocene. The brownish beds represent the lower (Vaqueros) and middle Miocene (Topanga) formations. The overlying light-gray beds represent the upper Miocene (Modelo formation), here remarkably thin, and consist largely of diatomaceous shale, which gives them the light color. The section can be seen in more detail in Grimes Canyon, south of Fillmore.

Moorpark to Oak Ridge.—Turning northward at Moorpark, in Little Simi Valley, which is one of the eastward extensions of the Ventura Basin, the route leads up a shallow canyon cut into relatively unconsolidated Pleistocene sand and conglomerate (Saugus formation). At the head of this canyon the road lies on a broad plain or terrace, covered with a deposit of later Pleistocene sand and gravel, gently sloping southward. This plain was once a part of the floor of a much larger Little Simi Valley but has been dissected by northward-heading canyons. As the route ascends gradually to the summit of Oak Ridge, numerous road cuts give good exposures of the older coarse sand and gravel.

At the summit of Oak Ridge (altitude 1,425 feet, or 435 meters) the view northward overlooks the town of Fillmore and the valley of the Santa Clara River, another synclinal depression belonging to the same basin as the Simi Valley region. Directly northward is Sespe Creek, the type locality of the massive-bedded red sandstones and conglomerates of the Sespe formation (Oligocene and Eocene). A complexly folded series of sandstone, clay, and siliceous shale forms the grass and brush covered mountains for about 5 miles (8 kilometers) east of Sespe Creek. This is the type locality for the Modelo formation. West of Sespe Creek the high and rugged Santa Paula Ridge (altitude 4,800 feet, or 1,463 meters) is composed of Eocene strata, which

have a general northward dip that carries them beneath the Sespe formation. The lower hills are formed of comparatively soft rocks, mainly of Pliocene age (Pico and Repetto formations). The still lower gentle, smooth slopes are alluvial fans of Pleistocene and Recent age, which are now dissected by steep-walled ravines. The contact between the Eocene and Pliocene is marked by a major thrust fault known as the San Cayetano fault. It is plainly visible following the foot of the steep south slope of Santa Paula Ridge at an altitude of 2,250 feet (686 meters). At the surface the fault plane dips about 45° N. The fault branches west of Santa Paula Creek as two separate faults, one lying along the base of the steep front of Sulphur Mountain and the other extending through Upper and Lower Ojai Valleys. More details of these faults and the rock sections involved can be seen to better advantage farther west on the road from Santa Paula to Ojai.

Structure of Santa Clara Valley.—Oak Ridge itself is an anticline having a thrust fault along the north base. Like the rocks involved in the San Cayetano thrust, on the opposite side of the Santa Clara Valley, the older rocks here (Oligocene and Miocene) override Pliocene strata, but the plane of the fault dips southward. Thus the two faults oppose each other and tend to approach each other over a deep synclinal basin of Miocene, Pliocene, and Pleistocene strata. From the evidence of two wells drilled south of the fault, the plane has been found to dip 50°–60° S., with upper Pliocene beds lying beneath the Oligocene.

Stratigraphy of Santa Clara Valley.—Although the rocks now exposed on both sides of the Santa Clara River were deposited in the same basin, they differ considerably in lithology, as will be seen in the trip across the two sides. The cause of this dissimilarity probably lies in the great throw of these thrust faults, which is from 1 to 2 miles (1.6 to 3.2 kilometers). In general, the beds on the north side have a much greater degree of induration and are of greater thickness. The section forming Oak Ridge is excellently exposed along the road from the summit down Grimes Canyon to Bardsdale. The loose cross-bedded Pleistocene sand and gravel (Saugus formation) are exposed along the winding grade nearly to the bottom of Grimes Canyon. Lying below the sand, a small thickness of the Pliocene shales (Pico formation) is exposed, but the greater part of the Pliocene is here overlapped by the Pleistocene. To the west the section of Pliocene rocks thickens considerably, measuring over 3,000 feet (914 meters) within 4 miles (6.4 kilometers). The Pliocene rests unconformably on the Miocene diatomaceous

shale (upper part of Modelo formation), which usually has a light-gray color. In Grimes Canyon the beds have been locally burned to a dark-red color and in places even fused. This burning, which is still going on, is due to the combustion of escaping gas. This upper Miocene formation grades downward into the middle-lower Miocene section, composed mainly of sandstone, which is coarser in the lower part. In places mollusks of lower Miocene age are found in the basal sandstone (Vaqueros formation). It in turn grades into the underlying Oligocene nonmarine yellow, brown, and reddish-brown sandstones, conglomerates, and red and green clays (Sespe formation), which are readily recognized everywhere by their color. The Sespe is the oldest formation exposed along Oak Ridge and crops out in oval areas along the structurally higher parts of the Oak Ridge anticline. Although the whole section is not exposed on Oak Ridge, it is known from wells to be at least 5,000 feet (1,524 meters) thick.

Bardsdale oil field.—The Bardsdale oil field, west of the mouth of Grimes Canyon, is one of a series of fields lying along the north side of Oak Ridge. From east to west these fields are the Torrey Canyon, Shiells Canyon (Montebello), Bardsdale, and South Mountain. The fields are localized on domes along the general Oak Ridge anticline. All these fields produce from the Oligocene (Sespe formation). In the Bardsdale field, which was discovered in 1896, most of the wells are between 500 and 1,500 feet (152 and 457 meters) deep and produce from one zone about 400 feet (122 meters) thick.

Bardsdale to South Mountain.—At Bardsdale the route turns westward along the south side of the Santa Clara River, allowing an excellent view of the mountains on the opposite side. The trace of the San Cayetano fault can be easily followed as the line between the grass-covered lower hills of soft Pliocene and Miocene strata and the brown, hard, well-bedded Eocene section above.

Timber Canyon fan.—One of the best examples of alluvial fans is to be seen at the mouth of Timber Canyon. This canyon, one of the largest cut into the Pliocene on the north side of the Santa Clara River, has been completely filled with detrital material derived from the fault face above, formed by the San Cayetano thrust.

South Mountain oil field.—Six miles (9.6 kilometers) west of Bardsdale a side trip through the South Mountain oil field shows the character of the Oligocene beds (Sespe formation) and typical anticlinal structure along Oak Ridge. This field is one of the most picturesque in California, owing to the exceedingly

rugged or badland type of erosion which the area has undergone. A number of the locations for derricks are so inaccessible that all materials for drilling were transported to them by inclined railways. (See pl. 12.) Excellent views are obtained of this asymmetric fold, rather gentle on the south side but becoming steep and even overturned as the Santa Clara fault is approached along the river. This field also is an example of conservative development, as it is almost entirely owned by one company. It was discovered in 1916. The oil sands occur between depths of 600 and 3,000 feet (183 to 914 meters), all being in the middle and lower part of the Sespe formation (Oligocene) in a series of alternating sands and shales of which the oil-bearing portion constitutes from 30 to 100 per cent.

View from South Mountain.—From the South Mountain field, which is more than 700 feet (213 meters) above the valley floor, a magnificent view is to be had of the Eocene section on Santa Paula Ridge, the San Cayetano thrust fault, and the thick Pliocene section below. To the west of Santa Paula Creek, up which the observer is looking, is Sulphur Mountain, and south of it lies an unbroken section of Pliocene and Pleistocene sediments over 23,000 feet (7,000 meters) thick. Sulphur Mountain (pl. 13, *A*), composed of upper Miocene rocks (Modelo formation), is separated from the Pliocene by a fault, the lowest part of the Pliocene section being missing. Beyond Sulphur Mountain are the higher Topatopa Mountains, composed of Eocene strata similar to those in Santa Paula Ridge. The Topatopa Mountains, the east end of the Santa Ynez Range, lie directly back of Ojai Valley. From South Mountain a comprehensive idea can be obtained of the structure of the Santa Clara Valley, which is a huge synclinal trough composed of Tertiary and Quaternary strata. The Pliocene section alone is nearly 20,000 feet (6,100 meters) thick and can be seen in its entirety between Santa Paula and the San Cayetano fault. This section has been squeezed together between the two major thrust faults on the sides and overridden by older rocks. On the Oak Ridge fault the movement has been about 8,000 feet (2,440 meters) toward the north, whereas on the San Cayetano fault the Eocene rocks have moved for over 2 miles (3,200 meters) southward.

Santa Paula Creek section.—The town of Santa Paula, a walnut and citrus-fruit center, is situated on the north terrace of the Santa Clara River, back of which lies the thickest section of Pliocene in California. For a distance of 4 miles (6.4 kilometers) up Santa Paula Creek a section of Pleistocene and Pliocene, unfaulted and unfolded, is crossed at right angles to the strike.

SOUTH MOUNTAIN OIL FIELD

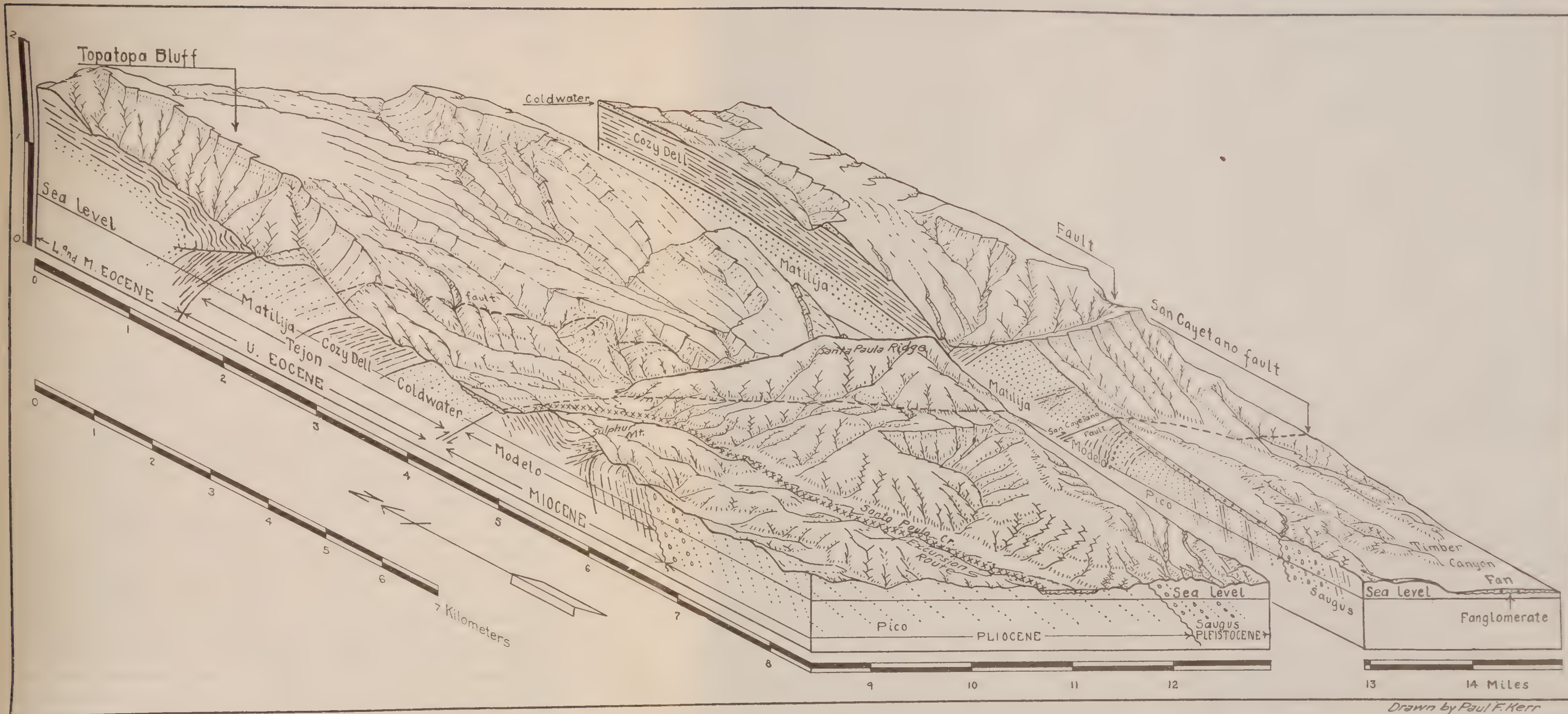
Showing axis of anticline and badland type of weathering in the Sespe formation.

A. SOUTH SIDE OF SULPHUR MOUNTAIN

Showing trace of fault and its scarp. Typical Modelo (upper Miocene) siliceous shale on right; brown shale member of Modelo and lower member of Repetto (lower Pliocene) on left of fault. Note hanging canyons and mature topography of crest.

B. SMALL REVERSE FAULT IN ROAD CUT ON NORTH SIDE OF RINCON CREEK, SANTA BARBARA COUNTY

Modelo (upper Miocene) shale is overriding unconsolidated sand of Pleistocene age.



TOPOGRAPHY AND STRUCTURE OF HIGHER MOUNTAINS NORTH OF SANTA PAULA

The dip ranges from 30° in the Pleistocene to vertical in the Pliocene but averages about 65° S. on the west side of Santa Paula Creek. The beds are steeper on the east side of Santa Paula Creek, and farther east they become overturned, owing to the southward pressure of the San Cayetano thrust. The section along Santa Paula Creek may be divided as follows:

	Feet	Meters
Quaternary terrace deposits: Conglomerate, nonmarine.		
Saugus formation (Pleistocene): Sand, conglomerate, and clay, mainly nonmarine	3,200	975
Pico formation (Pliocene): Gray siltstone with a few beds of sandstone and conglomerate	3,600	1,095
Repetto formation (Pliocene): Sandstone, conglomerate, and shale	12,900	3,932
Modelo (upper Miocene): Brown hackly shale (in fault contact with Pliocene).		
	19,700	6,002

Owing to the fact that the Pliocene section is faulted at the foot of Sulphur Mountain the lower part of the Pliocene section is missing. Ten miles (16 kilometers) farther west, near the Ventura River, where a normal contact with the Miocene is found, there is an additional 3,400 feet (1,036 meters) of lower Pliocene, which brings the total thickness to 23,100 feet (7,040 meters).

Sulphur Mountain fault.—Four miles (6.4 kilometers) north of Santa Paula, at the east end of Sulphur Mountain, the Miocene brown shale (upper member of Modelo formation) is exposed. A few shallow oil wells produce a small amount of oil from sandstone beds in this brown shale. The main part of the mountain is composed of Miocene (Modelo) shale, largely siliceous, and the underlying Miocene brownish-gray clay shale (Rincon formation). One of the faults of the Sulphur Mountain fault zone, a branch of the San Cayetano thrust fault, is plainly exposed in the road cut, where nearly black, sulphur-coated siliceous shales, highly contorted, are in contact with the older black shale. West of Santa Paula Creek the Sulphur Mountain fault is clearly outlined by the break in the profile of the south slope. (See pl. 13, *A*.) Above the fault the scarp is exceedingly steep and the rocks are the siliceous shale member of the upper Miocene, whereas south of the fault the topography is subdued and the strata are either of Pliocene age or belong to the brown shale member of the upper Miocene. An interesting feature of Sulphur Mountain is the relatively mature topography on the top, in contrast to the active dissection of the south face. The streams on top are entirely out of accord with the streams below, owing to the displacement along this fault, which has

left the upper stream beds hanging far above the general stream levels. (See pl. 13, *A*.)

San Cayetano fault.—Eastward across Santa Paula Creek the San Cayetano fault zone is disclosed from a different angle. Here can be seen the steep fault-line scarp in Eocene strata and also the relatively low dip of the fault plane, which extends up Santa Paula Creek. The Sulphur Mountain fault zone lies in Anlauf Canyon and joins the major fault several miles to the east of Santa Paula Creek. Sulphur Mountain is an upthrust block of Miocene formations lying between two faults. The south fault dies out near the west end of the uplifted block, where Sulphur Mountain is a southward-dipping homocline of Miocene strata lying normally below the Pliocene series and resting upon the Oligocene (Sespe) red beds.

Sisar Creek.—Passing the east end of Sulphur Mountain the road to Ojai Valley turns westward up Sisar Creek. It parallels the north side of Sulphur Mountain, at the base of which lies one of the faults of the San Cayetano fault zone. On the north side of Sisar Creek several oil wells have been drilled into upper Miocene and lower Pliocene beds. A small steady production is obtained from this faulted area.

Oil seepage.—Large seepages occur in the faulted area between the main San Cayetano fault at the base of the Topatopa Mountains and the north side of Sulphur Mountain. These seeps lie in a definite belt, which extends through the Ojai district for many miles. One of the largest occurs along the main highway in Sisar Creek, a short distance east of the Upper Ojai Valley. At this locality enough heavy oil accompanied by sulphur water has issued to cover an area of about an acre (0.4 hectare) and to extend down the hillside for several hundred feet. The oil exudes from the fractured upper Miocene siliceous shale.

Upper Ojai Valley.—The floor of Upper Ojai Valley is reached after a gentle climb to an altitude of 1,500 feet (457 meters) above sea level. Here a better idea can be obtained of the grabenlike structure of this valley, lying between the Santa Ynez Range and Sulphur Mountain. In the Santa Ynez Mountains there are good exposures of the upper Eocene rocks, especially in Topatopa Ridge (altitude 6,300 feet, or 1,920 meters), where over 3,000 feet (914 meters) of strata are exposed. The structure of this range is complex, but in general it is anticlinal, with the south limb or lower part overturned. (See pl. 14.)

At the west end of Upper Ojai Valley the road crosses the axis of a large anticline in the Oligocene red beds (Sespe formation), forming Black Mountain. From the axis of this fold southward across Sulphur Mountain a continuous section of Oligocene and Miocene is exposed.

Black Mountain grade.—The lithology of the Oligocene deposits is excellently shown in the road cuts on the grade leading from Upper Ojai Valley to Lower Ojai Valley. These northward-dipping strata form the north limb of the Black Mountain anticline. Near the bottom of the grade the red beds are overlain by light yellowish-brown thin-bedded sandstones and shaly sands, which represent the lower Miocene (Vaqueros formation). In many localities certain beds contain a molluscan fauna characterized by *Turritella inezana* and *Pecten magnolia*, two distinctive forms. One of the faults of the San Cayetano fault zone lies at the foot of this grade and extends westward along the north side of Black Mountain. Movement on this fault has caused the difference in altitude between the Upper and Lower Ojai Valleys.

Structure and stratigraphy of Lower Ojai Valley.—From the top of the Ojai grade the excellent view of Lower Ojai Valley shows that it is the larger and more deeply alluviated and, like the Upper Ojai Valley, is in general a graben. Large alluvial fans lie at the base of the high Santa Ynez Mountains, along the north side, upon which are located many beautiful estates. The structure of the mountains as a whole is that of an anticline with its south flank overturned toward the south. The range is composed of Cretaceous, Eocene, Oligocene, and Miocene strata.

Rocks of Santa Ynez Mountains

	Feet	Meters
Sespe formation (Oligocene)	5,500	1,676
Tejon formation (upper Eocene):		
Coldwater sandstone	2,000–2,500	610–762
Cozy Dell shale	1,500–2,700	457–823
Matilija sandstone	2,000–2,400	610–732
Middle and lower Eocene (undifferentiated)	4,300	1,311
Cretaceous (undifferentiated)	1,500	457

The Cretaceous is present only in the interior part of the mountains and is not visible from the valley. The Oligocene red beds can easily be discerned as a belt along the base of the mountains which is overlain in overturned relation by the nearly white Eocene sandstones and green and red clays (Coldwater sandstone); this is in turn overlain by the older Eocene beds (Cozy Dell shale and Matilija sandstone), all of which are included in the upper Eocene (Tejon formation). The total maximum thickness of the beds in this section north of Ojai Valley is about 18,900 feet (5,760 meters).

West end of Ojai Valley.—From the town of Ojai the road leads over the terrace-covered floor of the valley, where in some of the road cuts can be seen the upper Miocene shales. In one

road cut 4 miles (6.4 kilometers) west of Ojai is exposed a bentonite bed that marks the division between two Miocene formations (Modelo and Rincon). The older of these two (Rincon), which is exposed in the gulch below, is gray and rather massive and contains, in certain zones, yellowish, impure limestone nodules. Along the road descending from the Ojai Valley to San Antonio Creek near its junction with the Ventura River are good exposures of upper Miocene siliceous shale. In most places it is highly contorted, owing to intense folding and faulting in this vicinity.

Red Mountain.—From San Antonio Creek the road follows the Ventura River through a relatively narrow canyon between the west end of Sulphur Mountain and the east end of Red Mountain. Red Mountain rises high above the west bank of the Ventura River and structurally is a large domelike anticline. It is composed mainly of Oligocene (Sespe) red beds, though wells drilled on the mountain have penetrated the Eocene at depths as shallow as 1,050 feet (320 meters). Along the eastward-plunging end of this fold, which is cut by the Ventura River, is to be seen a representative section of the Miocene overlying the Sespe. South of the bridge over San Antonio Creek are the upper Miocene siliceous shales (Modelo) followed by gray clay shales (Rincon formation) at Rock Flat, which in turn overlie the lower Miocene (Vaqueros sandstone) in the vicinity of the Southern California Edison Co.'s substation at Casitas. At the junction of the Casitas Pass road the lower Miocene sandstone and overlying shale are exposed on the south limb of the anticline.

Red Mountain is a mass of lower Miocene and older rocks upthrust against younger strata and is almost entirely circumscribed by faults. On the south side of the mountain the Oligocene red beds and the lower Miocene sandstone have been thrust upward against the Pliocene section to the south. East of the Ventura River the upper Miocene is also in fault contact with the Pliocene. The abrupt change in slope and vegetation clearly marks the trace of this fault.

Ventura Avenue anticline and oil field.—From the Red Mountain fault southward to the ocean the strata exposed are entirely of Pliocene age except for a small thickness of Pleistocene back of the city of Ventura. This section has been folded into the Cañada Larga syncline and the Ventura Avenue anticline. The anticline extends westward from the valley of the Santa Clara River north of Saticoy to Punta Gorda, on the coast 12 miles (19 kilometers) north of Ventura, a distance of 18 miles (29 kilometers). The Ventura Avenue oil field, one of the

largest in California, is located on this anticline and is cut through the center at right angles by the Ventura River, where the arch of the fold can be plainly seen on each side. The apex of the structure is also below the river bed. The wells start in the lower Pliocene (Repetto formation), and the deepest well in the field has penetrated 9,710 feet (2,960 meters) and is still in Pliocene strata, from which it is producing. There are four oil zones, though on the top of the fold no sharp divisions of oil-bearing formations or water sands can be made. The uppermost or light-oil zone occurs only on the highest part of the structure, at a depth of 1,600 to 2,600 feet (488 to 792 meters). The top of the lowermost or Lloyd 57 zone occurs at about 8,300 feet (2,530 meters) and extends downward to the limit of present drilling depths. The Lloyd zone, which has yielded most of the production, is reached at a depth of about 4,300 feet (1,311 meters) and has a thickness of at least 2,700 feet (823 meters). The formation consists of uniformly alternating sandstone and shale, varying in texture and hardness. In other words, the strata in which the oil occurs are much like those seen in the surface exposures near the axis of the anticline. The total production of this field up to July 1, 1932, was 122,501,440 barrels (19,476,503,945 liters). At present the base of the Pliocene oil-bearing formation has not been reached, and it is thought that at least an additional 3,500 feet (1,067 meters) of Pliocene beds should lie below the bottom of the deepest well. Along the road near the south edge of the producing area a good exposure of lower Pliocene rocks is shown in a road cut and excavations for well sites. Some interesting minor faults can also be observed here. About midway between the field and the city of Ventura the large excavations on the east slope of the river have been made for the purpose of mining clay of upper Pliocene (Pico) age to use in making drilling mud. On account of high gas pressure, large quantities of this mud are needed for rotary drilling fluid in the Ventura field, as relatively little mud-making shale is found in the deeper oil-bearing formations. On the west side of the river a number of broad, clean-cut stream terraces lie at altitudes of 250 to 500 feet (76 to 152 meters), depending on the distance from the coast. From the axis of the anticline to Ventura a continuous southward-dipping section of the Pliocene and Pleistocene is seen.

The oil from the light-oil zone in this field has a gravity of 39° to 52° Baumé; that from the other zones, 29° to 31° Baumé.

Ventura coast and Rincon oil field.—At the mouth of the Ventura River, or at the city of Ventura, the route turns north-

westward along the ocean shore for a distance of 28 miles (45 kilometers) to Santa Barbara. For a distance of 11 miles (18 kilometers) from Ventura to Punta Gorda station, the formation exposed in the steep sea cliffs is mainly of upper Pliocene (Pico) age. It is a part of the south flank of the Ventura anticline, the crest of which finally passes into the ocean at Seacliff. The Rincon oil field is located on this fold and is partly on shore and partly in the sea. The fold here is asymmetric and somewhat complicated by reverse faulting on its north flank, owing to the influence of the Red Mountain fault, which is less than a mile (1.6 kilometers) from the coast at this point. Here, as in the Ventura Avenue field, the oil is derived from the lower Pliocene (Repetto formation), though at shallower depths. The top of the main zone lies at a depth of about 3,000 feet (914 meters) on the crest of the anticline. At first development took place on shore, but in 1930, after a geologic survey of the outcrops on the floor of the ocean, a long pier was built and wells drilled over the water. The depth of the water here is not more than 35 feet (10.7 meters).

Red Mountain fault.—At the south end of the causeway, between Punta Gorda and the Santa Barbara County line, at Rincon Creek, the Red Mountain fault can be made out on the sea cliff where it crosses into the ocean. To the north it parallels the coast and probably lies beneath the small delta of Rincon Creek. North of the fault are upper Miocene (Modelo) diatomaceous shales, now colored red by the burning of escaping gas. These beds are greatly contorted and broken, permitting the gas to escape from the petroliferous strata below.

Channel Islands.—Unless fog interferes, it is usually possible to see from the Ventura County coast Santa Cruz Island and to the south the smaller Anacapa Island, which belong to the group of the Channel Islands. They are structurally a part of the Santa Monica Mountains and form the south side of the Ventura basin of Pliocene deposition. The rocks on these islands are mainly sedimentary rocks of Eocene and Miocene age, supplemented by Miocene volcanic rocks. On Santa Cruz Island are exposed areas of both schist and granite, probably of Mesozoic age.

Rincon Creek to Summerland.—After crossing the bridge over Rincon Creek the road leads up a deep cut to the Carpinteria terrace or mesa. This cut has exposed typical diatomaceous and siliceous shales of upper Miocene age. Two faults are clearly shown. The southern one dips northward and separates two types of shale. The northern one, near the top of the grade, is a thrust in which the Miocene laminated siliceous shales have

been shoved over unconsolidated sand of late Pleistocene age, covering the terrace. (See pl. 13, *B*.) A thin bed of Recent sand, deposited by the wind after the faulting, unconformably overlies both the shales and the sand. The soft sand is disturbed only to a small degree, whereas the Miocene shales are folded in a drag over the sand. The fault also has its expression at the surface in the sand ridges and intervening depression that extend northwestward toward the coast. This fault is one of several relatively minor faults which are directly related to the Red Mountain thrust fault, the main break being to the south.

From the Carpinteria terrace, on the west side of Rincon Creek, there is a different view, which is more nearly like that at Ojai Valley. From Rincon Creek to Santa Barbara and northwestward to Point Concepcion the high Santa Ynez Mountains rise abruptly from the terrace and low foothills. These mountains are for the most part composed of Eocene rocks, with minor thicknesses of Cretaceous, Oligocene, and Miocene. In general the structure is anticlinal, but this is complicated in most places by faulting and accompanying overturning, as can be seen directly back of Santa Barbara. A prominent line of foothills extends westward from Rincon Creek, back of which lies one of the large faults of this district, the Arroyo Parido fault. It continues beyond Summerland through Montecito and Santa Barbara. At Summerland the beds in these foothills comprise the entire Miocene section, but back of Santa Barbara only the upper Miocene shales are present.

Summerland oil field.—One of the oldest oil fields of the State is located on the beach at Summerland. Although there are at present several producing fields offshore in Ventura and Santa Barbara Counties, the Summerland field was the first to be drilled in the ocean. The oil is obtained at a depth of 1,000 to 1,300 feet (305 to 396 meters) from the lower Miocene (Vaqueros) and Oligocene (Sespe) sands. In this respect the Summerland field is similar to the Elwood and Capitan fields along the west coast west of Santa Barbara. The wells are small, most of them having an initial daily yield of less than 200 barrels (31,798 liters) of 20° oil. The general structure of the field is that of a seaward-dipping anticline closed against a fault near the shore. The beds exposed at the surface are of upper Pliocene age, overlying unconformably the middle Miocene (Rincon) shale. These Pliocene strata, which are unconformably overlain by Pleistocene gravel, are well exposed in the road cut at Ortega Hill, west of Summerland, where the Pliocene-Pleistocene unconformity is clearly visible.

From Summerland to Santa Barbara the road passes over the low sea terrace cut into the Pleistocene gravel deposits, some of which are tilted, as shown in the cut near the Montecito Inn.

Santa Barbara.—The city of Santa Barbara is situated in a graben between the Arroyo Parido fault on the north and a fault along the north side of the hills on the southwest. This graben extends northwestward to Goleta and is a major structural feature of this part of the coast. Other large faults exist also in this district, and it is probably along one of these numerous faults that the Santa Barbara earthquake originated. At the Santa Barbara breakwater there is a good exposure of upper Pliocene strata that contain a distinct molluscan and foraminiferal fauna, commonly referred to as the "Bathhouse Beach fauna." Southwest along the sea cliff a good section of middle Miocene (Rincon) and upper Miocene (Modelo) is easily accessible. At the contact of the two is the tuff bed, here about 25 feet (7.6 meters) thick, which is a persistent marker at this horizon over Ventura and Santa Barbara Counties.